THE VICTORIAN MALLEE SYMPOSIUM

9 SEPTEMBER 1965

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FOREWORD

A one-day symposium on the Victorian Mallee was held on 9 September 1965. The Mallee makes up about 15 per cent of the area of the State; its extent is variously defined, as shown in the succeeding Fig. 1. It is the driest region of the State, and the annual rainfall is shown in Fig. 2, a specially prepared map for which we are grateful to the Commonwealth Bureau of Meteorology. The object of the symposium was to bring together the many kinds of scientific information available on the Mallee and to stimulate further research through discussion. This symposium was organized along the lines of two previous symposia, on the High Plains of Victoria (published in Vol. 75 of the *Proceedings*) and on the basalt plains of Western Victoria (published in Vol. 77 of the *Proceedings*).

The 9 succeeding papers (No. 32-40) were given at the symposium.

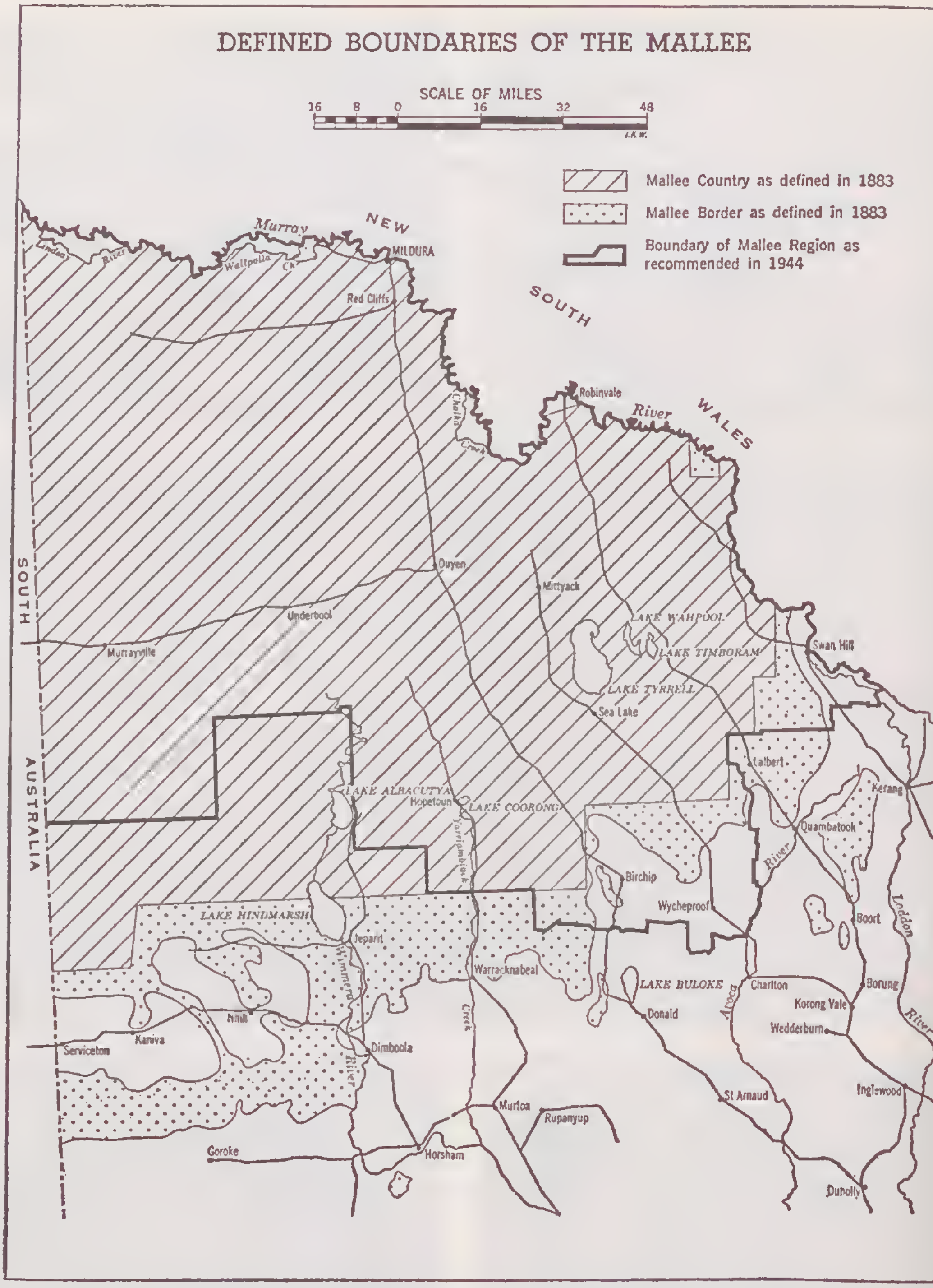

Fig. 1—The Victorian Mallee, showing rivers and railways and the boundaries as variously defined.

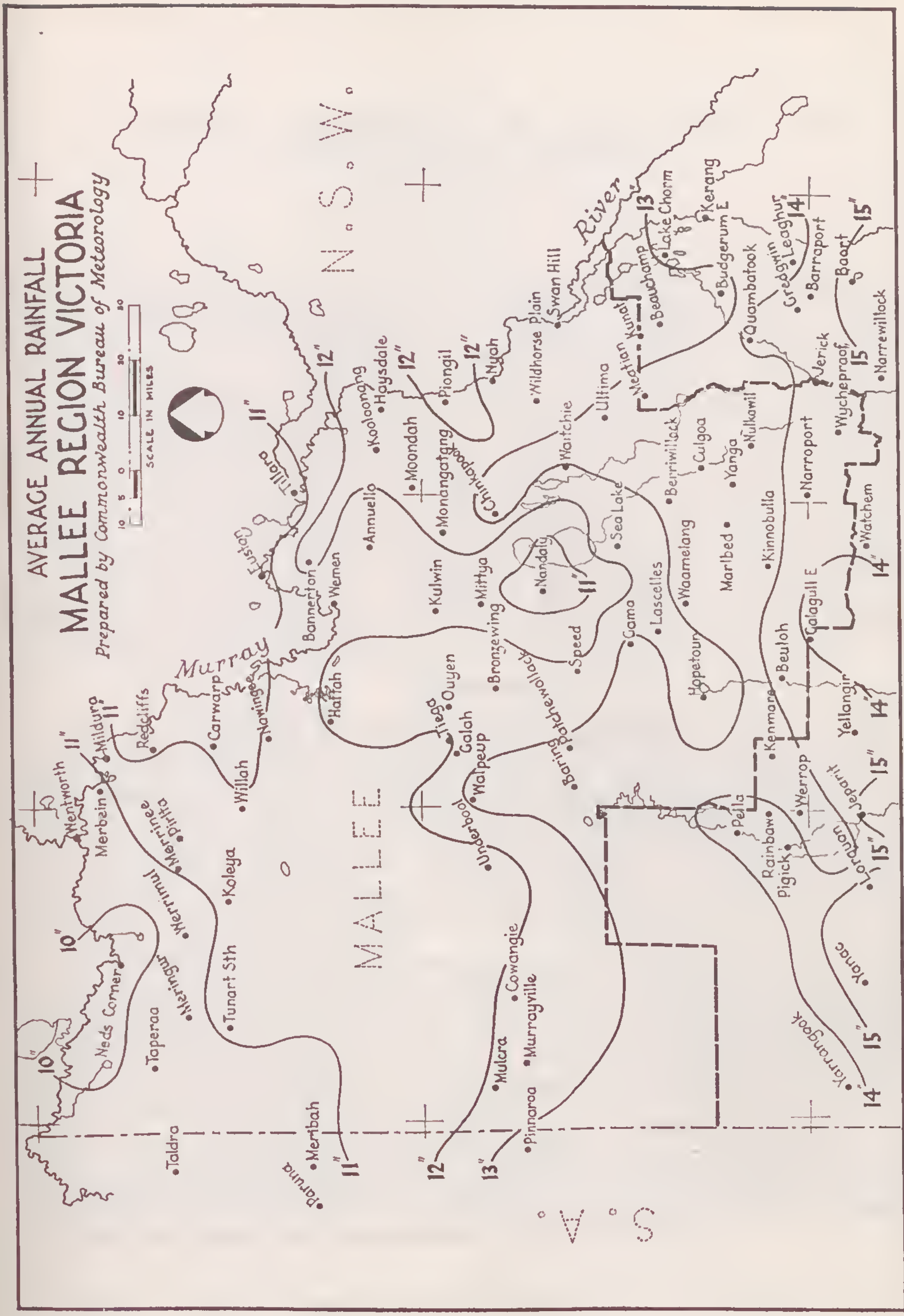

FIG. 2—The Victorian Mallee, showing annual isohyets and the boundaries recommended for the Mallee Region in 1944.

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CAINOZOIC STRATIGRAPHY AND STRUCTURE OF THE MALLEE REGION, VICTORIA

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Abstract

The Tertiary history of the Mallee Region is intimately related to the migration within the Murray Basin of Eocene to Pliocene seas and rivers over a terrain of subdued to near-planar topography bevelling Cambrian-?basal Ordovician, Permian, and Lower Cretaceous sediments. The Tertiary sequence is complex, with facies relationships between a series of lithological units varying from neritic limestones (Duddo Limestone), shallow near-shore marine clays and marls (Netherby Marl, Geera Clay, Winnambool Formation, Bookpurnong Beds), paralic sediments (Knight Group), and non-marine fluviatile sands, silts, and clays (Wunghnu Group). The marine units are grouped as the Murray Group in contradistinction to the underlying paralic Knight Group and the non-marine Wunghnu Group on the landward side. The littoral marine Yanac Member at the base of the Netherby Marl represents the initial rapid transgression of the Murray Group; the regressive phase is expressed in part by the Diapur Sandstone, interpreted as a complex of stranded coastal features whose ridge topography represents successive stages of the regression. The Quaternary sequence is a complex of aeolian and fluvio-lacustrine sediments, divided in a sequence of thin units and members: Lowan Sand, Woorinen Formation (6 members), Blanchetown Clay and Bungunnia Limestone, Shepparton Formation (6 members), Coonambidgal Formation, and lunettes; the sequence being terminated by late Pleistocene to Recent evaporites (calcite, halite, and gypsum). The Shepparton and Coonambidgal Formations constitute the higher part of the Wunghnu Group. Many of these formation names are new; the members are adapted from previous informal usage by soil scientists.

Introduction

The area discussed in this paper covers the Mallee Region, an official resources district comprising 14,394 square miles of NW. Victoria and constituting just under 15%, by area, of the large sedimentary unit known as the Murray Basin (Fig. 1). The Tertiary sediments of the basin range in age from Lower?-Middle Eocene to Recent and include clay, silt, sand, gravel, marl, limestone, lignite, and glauconitic sediments. They are classified into rock units which generaly thicken and dip gently towards a point immediately W. of the NW. corner of Victoria. The main pre-Tertiary units consist of Lower Cretaceous marginal marine sands and shales, probable Lower Permian fluvioglacials, granites of unknown age, and Cambrian to early Ordovician metasediments.

Two distinct Tertiary depositional sequences are recognizable. These may correspond with the two youngest depositional cycles of the four-cycle system discriminated by Bock & Glenie (1965) for the Late Cretaceous to Tertiary sequence of the Otway Basin. For the youngest sequence in the Murray Basin there are some striking similarities with cycle 4 in the Otway Basin, but uncertainties exist with equating the earlier sequence—it has the broad time equivalence of cycle 3 but shows closer lithological affinities with cycle 2.

The main difference between the two sequences in the Mallee Region is that the older one consists essentially of carbonaceous clastics, whereas the younger sequence consists predominantly of calcareous rocks. Tertiary sedimentation in the Murray Basin was connected with gravity sag, which determined its geographical location, and perhaps with regular eustatic changes of sea-level.

Because the Tertiary sediments in the Mallee Region are almost completely buried by a veneer of Quaternary sediments, our knowledge of them is derived mostly from drilling. There are few publications on the subsurface geology of the Mallee Region; the main ones are: Chapman (1916), on the lithologic and palaeontologic description of samples from a line of 11 bores extending eastward from Panitya to Tutye; and Gloe (1947), who has given an exhaustive compendium of bore-hole data from private and official bores in the Mallee, Wimmera, and Glenelg Regions, and the hydrogeological interpretation of this data.

Since these publications, numerous deep bores have been sunk in the Mallee Region by the Victorian Mines Department as part of a groundwater survey of that Region. Because this drilling programme has been directed primarily for groundwater exploration and because the Murray Basin is relatively shallow, percussion plants have been used almost exclusively in preference to rotary drills; accordingly, sludge samples are virtually the only record of the strata passed through. The only rotary drilled holes in the Mallee Region from which cores of the strata have been taken are Olney No. 1, in the far NW. corner, and Mournpoull No. 1 at Hattah. These two bores are also the only ones in the Mallee Region to be electrically logged. Bore-hole data from the surrounding areas outside the Mallee has been studied to supplement this data.

The stratigraphy of the Cainozoic sediments in the Mallee Region is related to that in the neighbouring regions; where possible I have attempted to apply this work. For those portions of South Australia and New South Wales adjacent to the Mallee Region, the main published contributions are by Kenny (1934), Ludbrook (1961), Mulholland (1940), O'Driscoll (1960), and B.M.R. Publication 52, Petroleum Search Subsidy Acts (1964). The Tertiary stratigraphy of the Mallee Region has been correlated as closely as possible with the sequence established for the South Australian portion of the Murray Basin by Ludbrook (1957, 1958, 1961, 1963). Although Hills (1939) described the physiography of NW. Victoria and of the Mallee Region in particular, little detailed mapping of the Quaternary sediments of the Murray Basin as a whole had been done until recent years. The main contributor to this work, in so far as it is applicable to the Mallee Region, is Butler (1950, 1956, 1958, 1959) who, from reconnaissance mapping, provided a means of subdividing outcropping Quaternary sediments of the Murray Basin on the basis of lithology, genesis, and paleosols. This pioneer work has been followed by Churchward (1960, 1961b, 1963a, 1963b, 1963c) who has subdivided the material of the E.-W. dune chains in the Swan Hill district by applying Butler's criteria for recognition of buried soils, and by Pels (1964) who has discussed the distribution and evolution of the 'Coonambidgal' of Butler (here used as Coonambidgal Formation) associated with the Murray River.

In the following outline of the stratigraphy of the Cainozoic sediments of the Mallee Region the emphasis is on lithology.

For the gross stratigraphy of the Tertiary sequence, Ludbrook's rock units are adopted where possible, but it has been necessary to redefine some of these and also to introduce new ones.

The discussion under the heading 'Quaternary' is subdivided partly by rock units and partly by geomorphic forms, e.g. lunettes. The formations of Quaternary age are broadly subdivided into two types of deposition, namely aeolian units (dunes, sheets, lunettes, source-bordering dunes), and alluvial units (pediment, channel, flood-plain, and lacustrine), marked at the top by a soil and commonly at the base by a disconformity. Each formation is, in turn, subdivided into members which are used in a similar sense to formations except that they may be only locally

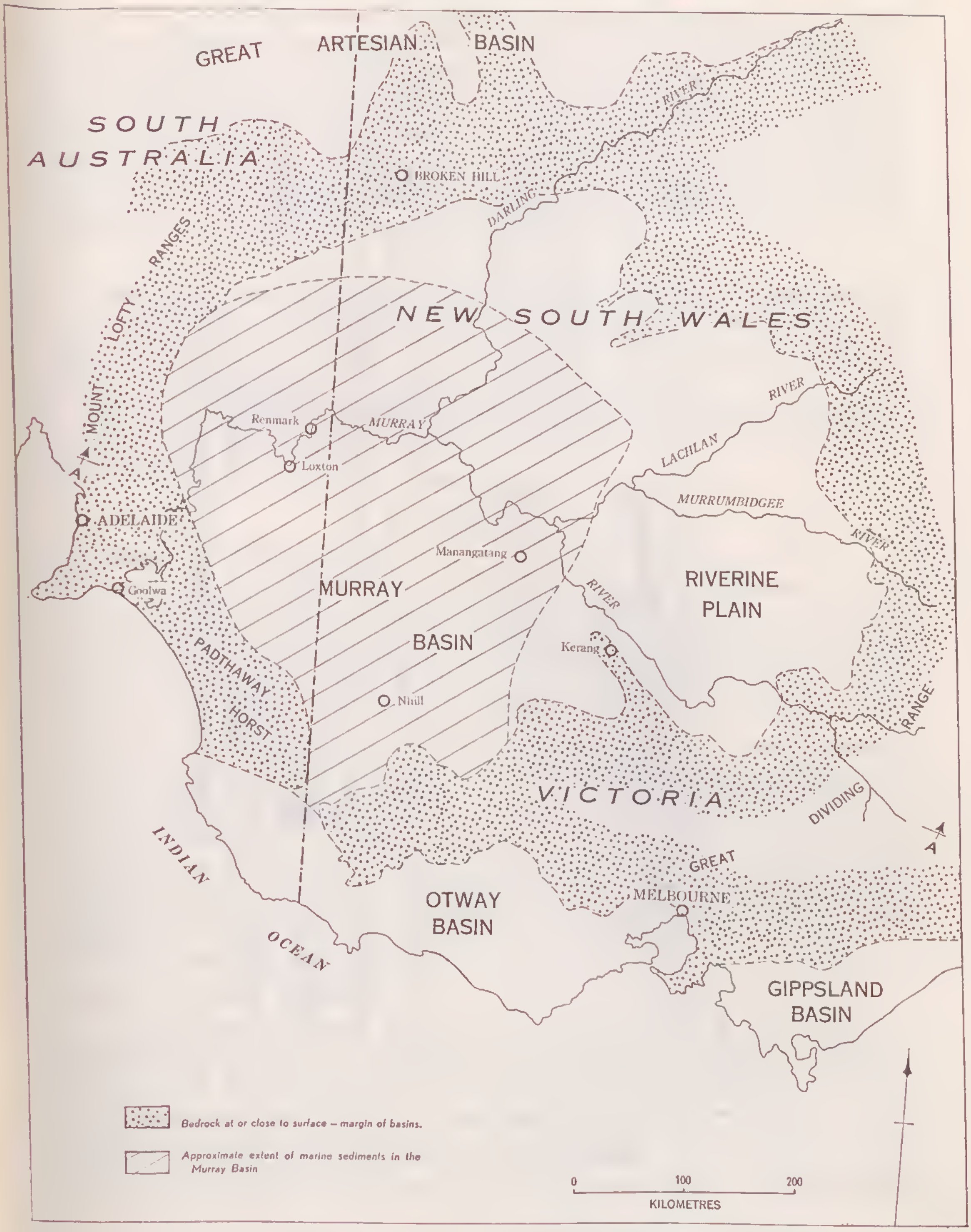

FIG. 1—Map of SE. Australia showing the location of the Murray Basin.

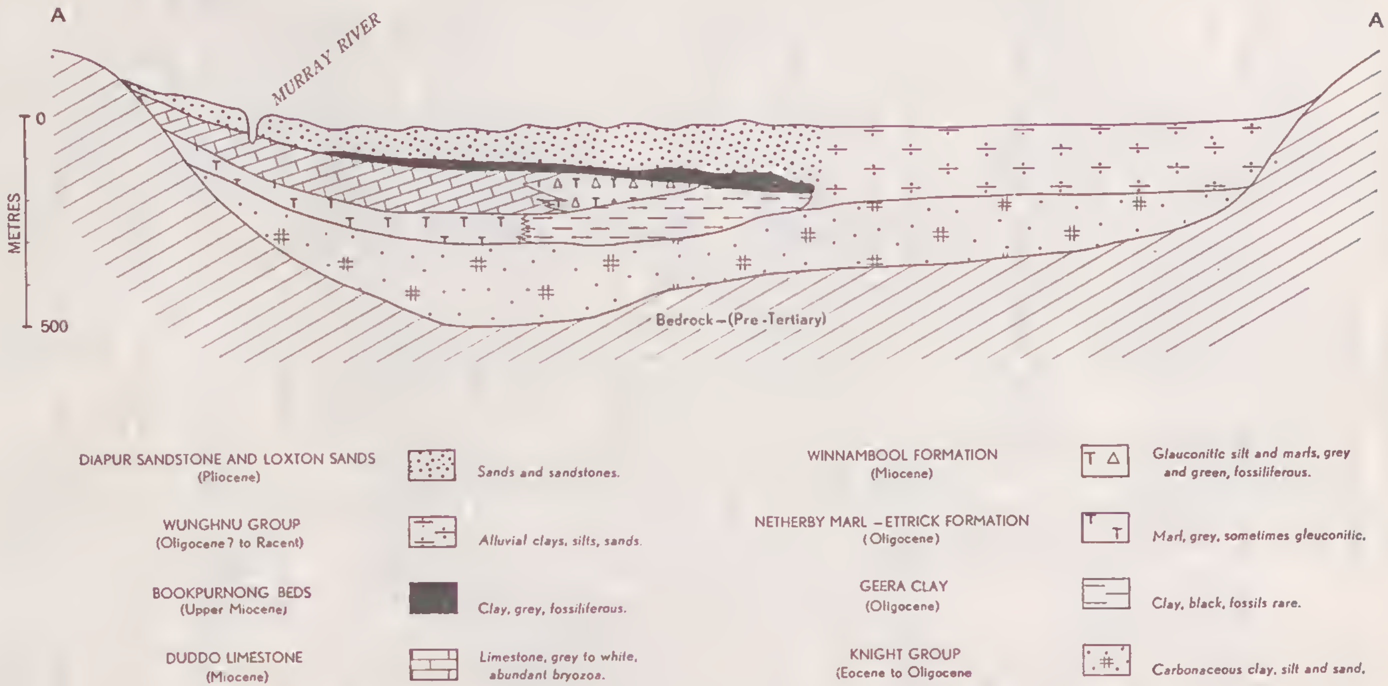

FIG. 2—Diagrammatic geologic section across the Murray Basin.

identifiable. Formal names used for members are adapted from the 'systems' and 'layers' of Butler and Churchward; these are regarded as more or less equivalent to members. The type locations and definitions by pedologists of these informal units are incorporated within the lithostratigraphic redefinition of members discussed in this paper. The soil designations K1s, K2s, K3s, K4s, and K5s, as defined by Butler (1959) are retained. The symbols of the K cycle are employed in this paper principally because they provide a means of communication between Quaternary geologists and stratigraphic pedologists working on the Murray Basin. In doing so, the author is aware of the undesirable connotations associated with the K cycle because of present widespread and indiscriminate use.

Acknowledgements

I gratefully acknowledge the guidance and interest of Dr D. E. Thomas, Director of Geological Survey. I am indebted to Dr J. A. Talent for his encouragement and constructive criticism of the manuscript. I have benefited from discussions with Messrs P. E. Bock, R. C. Glenie, M. W. Johns, and P. G. Macumber. Mr M. W. Johns also participated in the field work during the early stages.

Mr W. A. Esplan electrically logged the bores and advised on the interpretation of these logs; Mr D. J. Taylor identified Foraminifera and Mr J. G. Douglas identified fossil plant material.

Stratigraphy

Basement Rocks

Cambrian? Metasediments

Underlying the Mallee Region, and invariably buried with angular unconformity beneath the Knight Group are metamorphics of probable Cambrian to Lancefieldian age derived from fine to medium-grained clastic sediments. Rock types listed in Johns & Lawrence (1964) include shale, slate, phyllite, and sericite schist. Intruding these metasediments are granite bodies and quartz veins. Granite outcrops in the E. portion of the Mallee Region at Wycheproof, and near L. Boga where it shows copper and uranium mineralization.

When buried, the Cambrian? metasediments and granites are highly weathered to white, grey or buff clay; this material has been cored from only one bore in the Mallee Region—Mournpoull No. 1. The weathering process may be attributable to either the action of the acidic, bicarbonate-rich groundwater in the Knight Group acting on the basement rocks, or aerial and chemical weathering of the basement rocks prior to their burial. The composition of the weathered basement rock is generally kaolinite and quartz, but only in two cases has its composition been analysed by the X-ray diffraction method. The composition of weathered sericite schist from a depth of 1,370-1,380 ft in the Walpeup No. 2 bore was muscovite 40%, kaolinite 40%, and quartz 20%.

Lower Permian? Sediments

Lower Permian sediments have not been encountered so far in drilling in the Mallee Region; however, it is inferred from what is known from surrounding areas that they are present. Immediately S. of the Mallee Region at Netherby in Warraquil No. 1 bore, 1,385 ft of tillite and sandstone were encountered between the depths of 981 and 2,366 ft; in New South Wales, the Wentworth No. 1 bore encounted silty clay to siltstone of Permian age between 1,604 and 2,055 ft, and conglomerate of Permian? age between the depths of 2,055 and 2,081+ ft; in South Australia, the North Renmark bore encountered glacial marine sediments between the depths of 3,245 and 4,018 ft.

Lower Cretaceous Sediments

Lower Cretaceous sediments have been penetrated in the Mallee Region only in the Olney No. 1 bore where a fissile, grey sandy siltstone was struck beneath Eocene sands of the Knight Group between 1,992 and 2,015 ft, at which depth the bore bottomed. A core taken between 2,001 and 2,013 ft contained both plant remains and arenaceous Foraminifera indicating an Albian-Aptian age. J. G. Douglas (pers. comm.) reports: 'Microspores included *Cicatrecosisporites australiensis* (Cookson) Potonié, *Lycopodiumsporites austroclavatidites* (Cookson) Potonié, *Coptospora paradoxa* (Cookson & Dettmann), *Rouseisporites reticulatus* (Pocock), *Aequitriradites* sp., *Microcachyridites antarcticus* (Cookson), *Pyrobolospora reticulata* (Cookson & Dettmann). Cuticular remains derived principally from remnants of

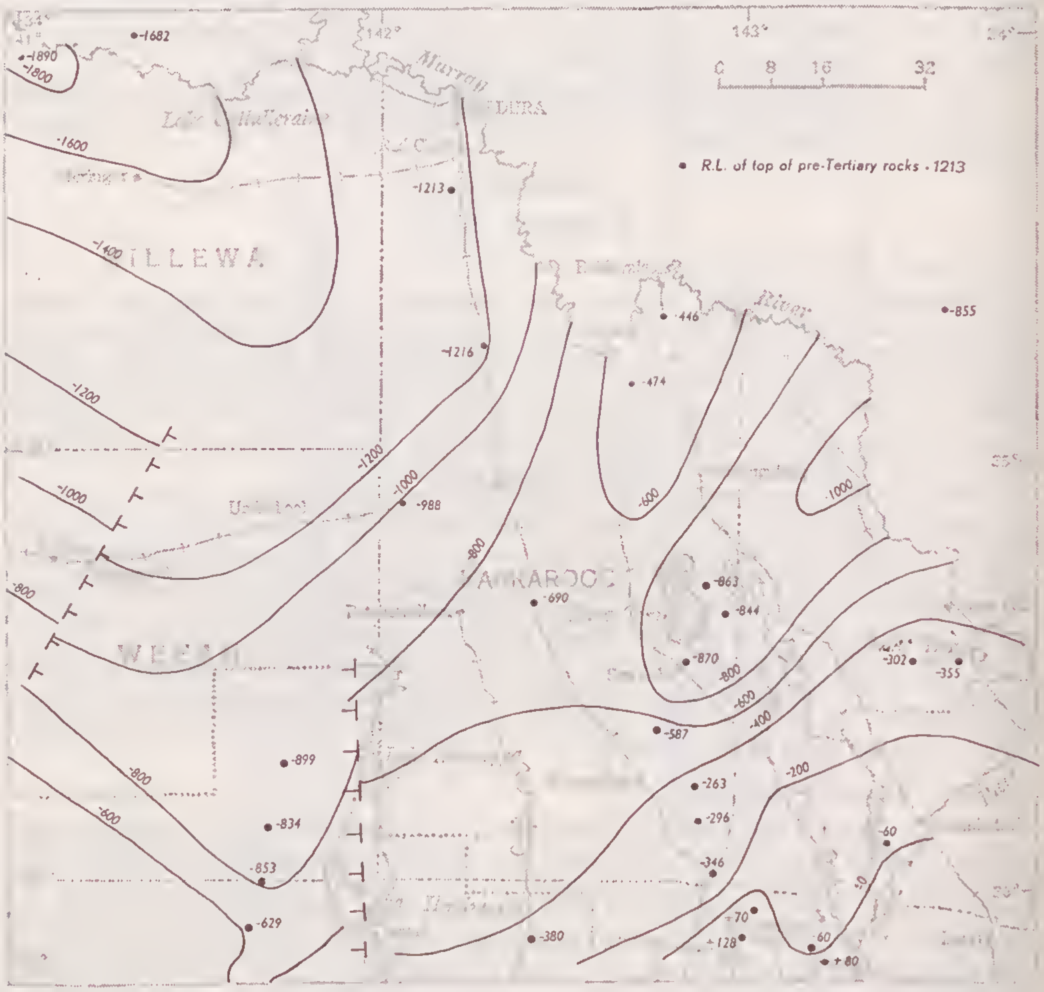

Fig. 3—Structure contours of the pre-Tertiary surface of the Mallee Region.

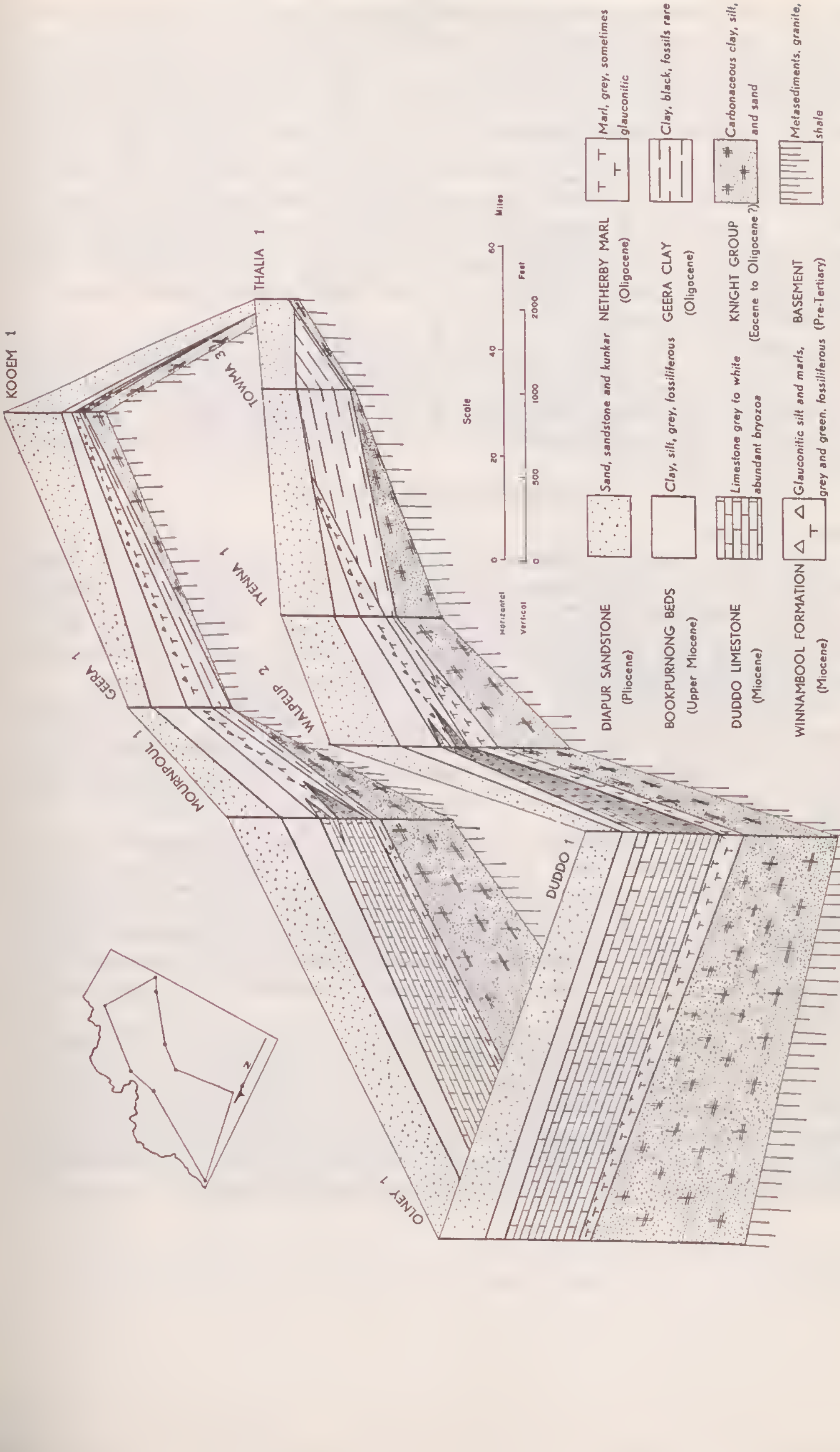

FIG. 4—Panel diagram of Tertiary rock-units in the Mallee Region.

large strap-like conifer leaves and a small-leaved *Brachyphyllum* type conifer were common. The microspore-megaspore remains indicate that the sample belongs to the *Paradoxa* Assemblage of Dettmann (1963) which she regards as belonging to the uppermost stages of the Lower Cretaceous. The cuticular remains (two types of conifer leaves) have been isolated from a number of localities in Western Victorian sediments also regarded as upper Lower Cretaceous in age (Douglas MS)'.

Although the Lower Cretaceous sediments were only partially penetrated in this bore, there are two bores adjacent to the Mallee Region in neighbouring States which have fully penetrated the Lower Cretaceous sediments. They are the North Renmark No. 1 (S.A.) and the Wentworth No. 1 (N.S.W.); in each case the Lower Cretaceous sediments, whose thicknesses were 840 ft and 331 ft respectively, rested unconformably on Lower Permian sediments (B.M.R. 1964). The Lower Cretaceous sediments in the far NW. corner of the Mallee Region probably occupy a similar stratigraphic position.

Ludbrook (1961) and the B.M.R. (1964) have implied correlation of the Lower Cretaceous sediments in the Murray Basin with those in the Great Artesian Basin. Indeed, it seems likely that the inundative phase of the depositional cycle responsible for the Rolling Downs Group also affected the Murray Basin area, depositing terrestrial and marginal marine time equivalents of the Roma Formation and the Tambo Formation.

Tertiary Sediments

Knight Group

The Knight Group, as defined by Sprigg (1952) and Boutakoff & Sprigg (1953), is a series of sands and carbonaceous sediments forming the lower part of the Tertiary sequence. Outcrops of the Knight Group are restricted to the raised belt of Tertiary rocks at the junction of the Otway Basin and the Murray Basin. It is in this belt, near Mt Gambier, but within the Otway Basin, that Boutakoff & Sprigg (1953) selected Knight's Quarry as the type locality of the Group.

The junction of the Knight Group in the Mallee Region with the underlying rocks may be either unconformable or disconformable. Where the underlying rocks are the tightly folded Cambrian? metasediments and their granite intrusives the junction is in angular unconformity. Elsewhere, for relatively small areas, the Knight Group rests disconformably on Lower Cretaceous sediments and probably on Lower Permian sediments.

The lithologies of the Knight Group include fine to medium-grained quartz sands; silts and siltstone which may be carbonaceous, dolomitic, or calcareous; clay, usually carbonaceous; and lignite. Pyrite and marcasite, both in authigenic and disseminated forms, are important accessories. The various rock types form an array of alternating and intertonguing strata for which there has been insufficient reliable information to establish stratigraphic subdivision. However, the calcareous and dolomitic siltstones appear to be almost exclusively restricted to the upper part of the Knight Group.

Preserved in the carbonaceous clays and lignite, but absent from the coarser clastics, is a rich assemblage of pollen derived from the temperate and tropical terrestrial plant genera *Casuarinidites, Myrtaceidites, Nothofagus, Proteacidites,* and *Triorites.* Marine fossils, almost exclusively the Foraminifera *Cyclammina* and *Cibicides,* are very rare. They are usually restricted to the upper part of the Knight Group in the W. part of the Mallee Region. Elsewhere, the lack of marine fossils, the variable lithologies and thicknesses, the poor sorting of many of the clastics,

TABLE 1

Cainozoic Stratigraphy of the Mallee Region

AGE		CLIMATIC EPISODES	← west	AEOLIAN			ALLUVIAL	east →	
QUATERNARY	Recent	Man's influence		Lowan Sands	Woorinen Formation	Piangil Member	WUNGHNU GROUP		Coonambidgal Formation (several phases)
		Arid				Kyalite Member			
		Humid / Arid				Speewa Member		Shepparton Formation	Mayrung Member; Widgelli Member (aeolian); Quiamong Member
		Humid / Arid	? ↑			Bymue Member			Katandra Member
	Pleistocene	Humid / Arid	Bungunnia Limestone; Blanchetown Clay			Miralie Member			Kialla Member
		Humid / Arid				Unnamed Member			Unnamed Member

AGE			LOCAL STAGES	MARINE INFLUENCE	Western-part Mallee Region	Eastern-part Mallee Region	NO MARINE INFLUENCE Northern Plains	
TERTIARY	Pliocene	U		MURRAY GROUP	Diapur Sandstone		WUNGHNU GROUP	Wyuna Sandstone
		L	Kalimnan					
	Miocene	U	Mitchellian and Cheltenhamian		Bookpurnong Beds			
		M	Bairnsdalian		Duddo Limestone	Winnambool Formation (↓ ?)		
		M	Balcombian					
		L	Batesfordian					
		L	Longfordian					
	Oligocene	U	Janjukian		Netherby Marl; Yanac Member	Geera Clay		? ↑ KNIGHT GROUP
		M · L						
	Eocene			KNIGHT GROUP				

Note:- Although boundaries of rock units in the table are represented as synchronous ones, some are known to be diachronous and the lack of continuity of strata indicate a non-marine environment of deposition —probably including fluviatile, lacustrine, and paludal types.

Only a broad Lower Tertiary age based on palynological evidence can be assigned to the Knight Group of the Victorian portion of the Murray Basin. Foraminifera present are *Cyclammina* and *Cibicides* which are long ranging species. However, it is considered, on micro-fossil evidence available, that deposition of the Knight Group in the Mallee Region began in the Lower Eocene and terminated in the W. portion of the Mallee Region in the Upper Eocene. The Knight Group in the Murray and Otway basins seems to be in part the landward equivalent of the marine-influenced Buccleuch Group (Ludbrook 1963) and the marine Nirranda Group (Bock & Glenie 1965). It is of similar facies to the Wangerrip Group but much of it appears to be younger than the latter in its typical development in the

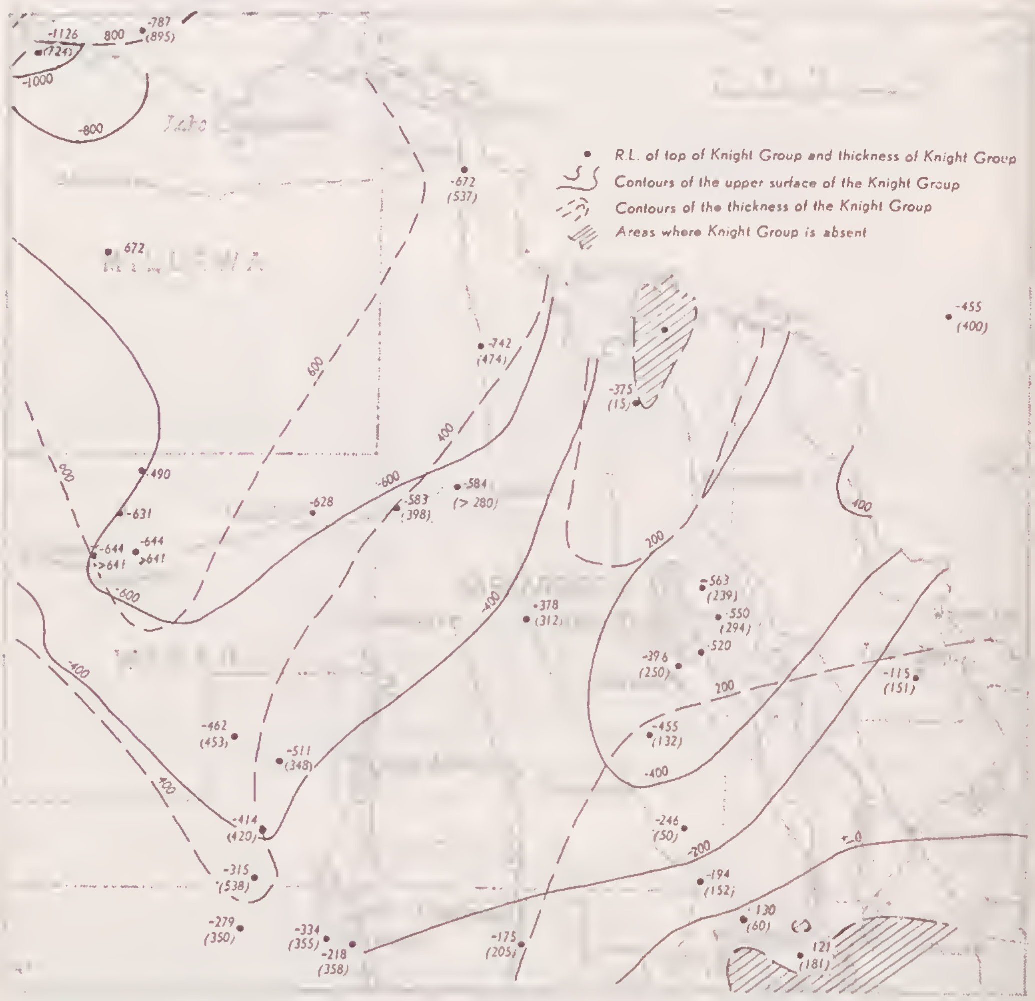

FIG. 5—Structure contours of the upper surface and isopach contours of the Knight Group in the Mallee Region.

W. Otway Basin and, unlike the latter, is not known to extend down to Paleocene and older horizons in the Murray Basin.

The Knight Group extends as an almost continuous unit throughout the entire Mallee Region, except where prominent bedrock 'highs' have precluded Knight Group sedimentation. Outcropping granite 'highs' at Wycheproof and L. Boga have prevented deposition of Knight Group sediments over small areas. In the Robinvale-Winnambool district, two bores—Bumbang No. 1 and Geera No. 1, the only bores to bedrock in that district—each traversed less than 10 ft of sands and gravel (Knight Group?) above bedrock. From geophysical and hydrogeological studies there is good evidence that this bedrock high, accompanied by the virtual exclusion of Knight Group deposition, extends northward from Winnambool into New South Wales.

From isopachs of the Knight Group in the Mallee Region (Fig. 5) it can be seen that it generally thickens towards the north-west. For example, it is 60 ft thick at Thalia in the far south-east and 724 ft thick in the far north-west in the Olney No. 1 bore. However, this trend is not constant. The main irregularity is the thickening of the Knight Group in the Piangil district to about 400 ft, a figure based partly on the author's stratigraphic interpretation of the logs of the Bundy No. 1 bore (N.S.W.) and the Balranald No. 1 bore (N.S.W.) published by the B.M.R. (1964).

Structure contours of the upper surface of the Knight Group have also been drawn (Fig. 5), but their value for interpretation of the history of the Mallee Region is dubious because the upper surface of the Knight Group, as presently defined, is diachronous. Nevertheless, some anomalies in the regional dip of the upper surface of the Knight Group are interpreted as being of tectonic rather than facies origin, e.g. the upper surface of the Knight Group is more than 150 ft lower on the E. and downthrown side of the Danyo Fault (Johns & Lawrence 1964) than the W. and upthrown side of this fault; also the upper surface of the Knight Group is lower (by more than 100 ft) on the W. side of the Hindmarsh Fault. Another irregularity in the general regional trend is a broad and low syncline trending SW.-NE. beneath L. Tyrrell and Piangil into New South Wales.

Being the most widespread of the rock units of the Tertiary sequence in the Mallee Region, the Knight Group is contiguous with several overlying younger units. Hence, the criteria employed to discern the upper boundary of the Knight Group, which represents a regional disconformity, depend on the lithology of the overlying rock-units. Where the Knight Group is buried beneath Oligocene marine sediments (Netherby Marl including the Yanac Member, and the Geera Clay), the upper boundary is easy to pick by the first appearance, as one drills down, of clastics or carbonaceous sediments devoid or almost devoid of marine fossils. East of a line linking Birchip and Swan Hill, fossiliferous marine sediments are absent and instead there are continental clays, silts, sands, and gravels, which together comprise the Wunghnu Group, resting on the Knight Group. The sole criterion used to select the upper boundary of the Knight Group in this case is the first sign in depth of persistently carbonaceous sediments, although some of the overlying non-carbonaceous sediments may be lateral equivalents of Knight Group sediments beneath the marine sediments to the west.

In the W. part of the Mallee Region, the Knight Group is disconformable beneath Janjukian strata belonging to the Yanac Member of the Netherby Marl, or, farther E., to the Geera Clay. Still farther E., continental sediments belonging to the Wunghnu Group, whose exact age is unknown, overlie the Knight Group. This means that, although there is a definite upper limit in age for the Knight

Group in the W. part of the Mallee Region where marine sediments are present, the upper limit is not precise in the east where there are palaeogeographical grounds for inferring that the upper limit of the Knight Group may extend higher. It is conceivable that the transgressing Oligocene-Miocene sea was fringed by marshes in which there could have been carbonaceous sedimentation.

Murray Group

Where marine influence is apparent in the Murray Basin, the depositional cycle has been used as the basis of classification at the group level; the older cycle is known as the Knight Group; the younger calcareous cycle is referred to as the Murray Group. The term 'Murray Group' was introduced by Ludbrook (1957) for the Miocene sediments lying between the Bookpurnong Beds and the Ettrick Marl. Its use in this paper has been broadened to include, besides the Duddo Limestone, all Tertiary marine sediments younger than the Knight Group.

The oldest unit of the Murray Group is the Yanac Member of the Netherby Marl; it consists of glauconitic micaceous clay and sand containing reworked Knight Group material. The Yanac Member represents a rapid marine transgressive deposit. It grades upward into grey marls of the Netherby Marl which thicken both southward and eastward away from the NW. corner of the Mallee Region where the sea is believed to have been deepest during Oligocene times. Farther eastward, the Netherby Marl grades into the dark grey to black, slightly calcareous Geera Clay. Clay-sized and silt-sized terrigenous material had an adverse effect on the benthic fauna which is limited to only a few species of Foraminifera and turrittelids. This is followed by a more extensive marine trangression during which the Duddo Limestone, containing a diversified fauna, was deposited. The limestone may be classified as a calcilutite or as a biosparite (Folk 1959), in which there is a small proportion, always less than 12%, of clay or sand-sized terrigenous material. The limestone because of its high proportion of sparry calcite particles (generally 10μ to $20\ \mu$ in diameter), suggests a moderately high energy environment.

Eastward and landward of the Duddo Limestone is the glauconitic silty or marly Winnambool Formation which grades in turn into the black almost unfossiliferous Geera Clay. By comparing these sedimentary zones with the model produced by Irwin (1965) for epeiric clear-water sedimentation it is evident that, for the Mallee Region, there was an abundance of fine grained material available from an eastern source. Both the Winnambool Formation and Geera Clay are considered to have been deposited in a low energy environment. The abundance of terrigenous sands carried by river water is regarded as the prime cause of the poor and unusual fauna present in the Geera Clay.

The regressive part of the cycle is prolonged, indicating a gradual withdrawal of the sea. A succession of sediment types is represented. The glauconitic, fossiliferous and clayey Bookpurnong Beds overlie the Duddo Limestone and Winnambool Formation. Overlying the Bookpurnong Beds is the unfossiliferous Diapur Sandstone, silty near the base but sandy through the rest of the profile.

Netherby Marl—

The Netherby Marl is named after the township of Netherby (in the Wimmera Region) where the bore, Warraquil No. 3, serves as the type section.

The Netherby Marl is found only in the W. part of the Mallee Region: the Hindmarsh Fault marks its easternmost extent in the south; to the north its easternmost boundary probably trends NNW. to cross the Murray R. near Wemen. The thickness of this formation varies between 150 ft and 70 ft, thinning towards the north; its regional dip is towards the NW. corner of Victoria. Eastward, as shown in the geological section (Fig. 4) the Netherby Marl grades into the slightly calcareous, glauconitic clay and silt of the Geera Clay.

The dominant lithologic type of the Netherby Marl is marl, but, scattered throughout, sometimes there are thin beds of marly limestones (which may contain shelly fossils) and calcareous clays. Regionally, the Netherby Marl becomes more limey towards the centre of the basin, i.e. towards the NW. corner of the Mallee Region.

The mineralogical constituents of the Netherby Marl are clay, quartz, calcite, aragonite, glauconite, and chert. Clay and quartz grains are allogenic components —probably derived from redistributed Knight Group sediments and possibly from the weathering products of a variety of Palaeozoic rocks in the Central Highlands. The calcium carbonate is present as calcite and aragonite, mainly as microcrystalline sparry material, but also as the tests of fossils. Foraminifera are the dominant group, with Bryozoa, Mollusca, Pelecypoda, and Echinodermata present in much smaller numbers. Unlike the Foraminifera which are dispersed throughout the formation, the fossils of these other groups are usually concentrated in thin bands.

The presence of aragonite in significant amounts instead of calcite alone is probably because highly saline connate water entrapped in the Netherby Marl has retarded the conversion of aragonite to calcite. Nodules of dark grey chert, sometimes with included fossils, occur rarely and spasmodically in the Netherby Marl. Because fossils are included in these nodules it is thought that the formation of chert has been a post-depositional and diagenetic process.

A continuous sheet of whitish bryozoan limestone—the Duddo Limestone—rests conformably on the Netherby Marl throughout the Marl's entire extent in the Mallee Region. Outside the Mallee Region near the S. margin of the basin, the Duddo Limestone is irregularly preserved in relatively small areas; where the Duddo Limestone is absent, the Diapur Sandstone rests directly on the Netherby Marl. The junction between the Duddo Limestone and the Netherby Marl is clearly discernible in most drilled sections by the abrupt change from white permeable bryozoan limestone to a grey, impermeable marl; but there are some districts, such as the S. part of the Big Desert, where the junction is obscure because of a transition zone of interfingering thin beds of marl and limestone. In such cases, the upper boundary has been arbitarily selected as the first appearance of marl in depth within this transition zone.

Electric logs are useful in discriminating the boundary between the Duddo Limestone and the Netherby Marl. Opposite the Netherby Marl, the self-potential curve is relatively positive and the normal resistivity curve is uniformly low. By contrast, the normal resistivity curve is markedly higher and the self-potential curve is relatively negative opposite the Duddo Limestone. The differences in electric logs opposite these lithologies are caused principally by the contrast between permeable limestone and relatively impermeable marl, and by the higher salinity of the groundwater in the marls.

The distribution of the Netherby Marl and its biostratigraphy as outlined above differs from the preliminary picture presented by Gloe (1947) who suggested that the marls girdling the Dundas Highlands graded basinwards into limestones, thereby reflecting distance from the source of the terrigenous material. Recent biostratigraphic studies suggest that this change from marl to limestone deposition in late Janjukian times was a regional one involving the entire Murravian Gulf, presumably associated with tectonic activity as with the other Tertiary basins of SE. Australia.

From foraminiferal evidence based mainly on the sections in the Olney No. 1 and Coynallan No. 1 bores (situated outside the Mallee Region approximately 15 miles S. of Nhill) the Netherby Marl is correlated with the Janjukian stage. The following diagnostic Foraminifera were identified by D. J. Taylor from between 340 and 570 ft in the Coynallan No. 1 bore: *Globigerina apertura, G. ciperoensis, G. ouachitaensis, G. bispherica, G. rubra, G. triloba* (large aperture form), and *Globoquadrina dehiscens.* Palaeontologic and other evidence is pointing to the correlation of the Netherby Marl with the Ettrick Formation (Ludbrook 1957) found in the W. part of the South Australian portion of the Murray Basin. If, in the future, further evidence confirms this correlation then the senior synonym, Ettrick Formation, would be retained and the term Netherby Marl discarded.

YANAC MEMBER—

The Yanac Member, named after the township of Yanac, S. of the Mallee Region, refers to very glauconitic claycy or sandy units at the base of the Netherby Marl.

The presence of glauconite (or oxidized pseudomorphs after it) throughout the Yanac Member is diagnostic and is indicative of the depositional conditions, i.e. marine environment in a temperate to warm temperate climate, accompanied by slow sedimentation under moderately reducing conditions. It is inferred that these conditions existed during deposition of the Yanac Member and were aided by the micaceous and carbonaceous fractions of the Knight Group which constituted the floor of the sea over which the Yanac Member was deposited, since biotite is one of the basic ingredients for glauconite formation and carbonaceous material would help create reducing conditions. The Yanac Member represents the earliest part of the rapid Janjukian trangressive phase, and its lower boundary, on micropalaeontological evidence, appears to be synchronous.

The Yanac Member rests disconformably on the Knight Group. The junction of the Yanac Member and Knight Group is sharp and easily discriminated. The Yanac Member is a green or orange coloured, fossiliferous, calcareous, fine-grained sediment and thus contrasts with the grey sand or brown carbonaceous sediments of the Knight Gorup.

An oxidized rock unit at a similar stratigraphic position to the Yanac Member persists throughout much of the Otway Basin; in South Australia it is referred to as the Compton Conglomerate, and in Victoria as the Clifton Formation.

GEERA CLAY—

The Geera Clay receives its name from the parish of Geera in the E. part of the Mallee Region, where the bore Geera No. 1 provides the type subsurface section. This bore, drilled by the Mines Department during 1961, cut the proposed formation between 490 and 590 ft; therefore, it has a thickness there of 100 ft. The surface level at the bore site is approximately 215 ft. Lithologically, the Geera Clay throughout its type section is a light olive grey to dark grey, fossiliferous clay in which glauconite grains are common.

Regionally, the Geera Clay is an olive grey to dark grey clay or silt which generally contains a poor fauna. The darker clay resembles the richly carbonaceous clays of the Knight Group in appearance, but in the Geera Clay the dark colour is due to iron minerals, particularly disseminated FeS_2; very little carbon is present.

Glauconite and pyrite are the dominant iron minerals, with melnikovite, siderite, and possibly some organic-iron complex making up the remainder; gypsum is sometimes present. Carbonate is present as the tests of what is usually a sparse, depauperate fauna of Foraminifera and Ostracoda; lacking is the Bryozoa so common in most other Tertiary marine units of the Murray Basin.

It is concluded that the Geera Clay was deposited in a shallow marine and lagoonal situation to which terrigenous muds were added; this would account for the poor fauna and the lithology. The fact that the iron is almost exclusively present as the ferrous form implies that the Geera Clay was deposited under reducing conditions. In the shallow seas which prevailed at that time, there must have been sufficient organic matter, probably derived from sub-aerial Knight Group outcrops, to deplete the oxygen dissolved in the sea water and reduce any ferric compounds to ferrous ones.

Although relatively few bores have penetrated the Geera Clay—a situation arising from the depth at which it occurs, and the presence of saline groundwater in the overlying Winnambool Formation—it appears to be distributed over a broad arc, landward from the Duddo Limestone, from Nurrabiel (in the Wimmera Region) through Birchip and Nyah into New South Wales.

Both the Netherby Marl and the Geera Clay correlate, on micropalaeontological evidence, with the Janjukian stage. From this and other stratigraphic evidence it appears that, to the east and to the north, the Netherby Marl grades laterally into the Geera Clay. This facies variation is sharpest where influenced by the tectonic control of the Hindmarsh Fault.

Briefly, the Geera Clay is a Janjukian transgressive deposit onlapping and disconformably overlying the Knight Group. The boundary between it and the Knight Group is identified in the same way as that between the Netherby Marl and the Knight Group discussed above.

DUDDO LIMESTONE—

For the South Australian portion of the Murray Basin 'proper', Ludbrook (1957) introduced three limestone formations, the Pata Limestone, Morgan Limestone, and Mannum Formation, all included in the Murray Group. The type localities for all these formations are near the W. margin of the Murray Basin; the type sections of the Morgan Limestone and the Mannum Formation are exposed in cliffs of the Murray River, whereas the type section of the Pata Limestone is in a shaft near Loxton. These outcrops of limestone are interpreted as inner neritic and littoral facies, an opinion supported by their position in the basin and their fossil assemblage. In this part of the basin there have been interruptions to carbonate deposition expressed as localized disconformities or changes of lithology, e.g. the Finniss Clay, the Cadell Marl Lens, and the transition bed of glauconitic sandy marl between the Pata Limestone and the underlying Morgan Limestone at the type locality of the former.

Interruptions to the calcareous suite of sedimentation typical of the W. margin of the Murray Basin become less frequent, and eventually disappear deeper in the basin in Victoria. The exception is a thin and discontinuous marly and glauconitic bed, possibly equivalent to the Cadell Marl Lens, lying 30 to 70 ft below the upper surface of the Duddo Limestone. E.g., in the Olney No. 1 bore a marly limestone bed 27 ft thick occurs 67 ft below the top of the limestone. The limestone above this marl bed is usually characterized by large numbers of *Ditrupa* sp.

The rarity of changes in the limestone sedimentation in the Victorian part of the Murray Basin means that the limestone formations of Ludbrook (1957) cannot be lithologically discriminated there; recognition of their equivalents must await detailed palaeontological work. These limestone formations are accordingly regarded as members of a new all-embracing formation—the Duddo Limestone. It is named after the parish of Duddo immediately N. of Murrayville; the Duddo No. 8 bore is selected as the type section. The Duddo Limestone encountered in this bore between 252 and 609 ft consists of greyish-white limestone, varying in texture from fine to medium-grained and containing some sand-sized quartz grains; the dominant fossils are Bryozoa and Foraminifera.

The nature of the E. boundary of the limestone varies. North of about the latitude of Patchewollock the limestone grades eastward, with some intertonguing, into the marly and silty fossiliferous Winnambool Formation, but farther south the limestone pinches out rapidly to the east along a N.-S. line, and is replaced by the Winnambool Formation. This sharp facies change is accounted for by Cainozoic movement on a bedrock fault—the Hindmarsh Fault. Northward, towards the New South Wales-Victorian border, the Duddo Limestone becomes noticeably thinner, suggesting that it does not persist far into New South Wales. The E. boundary of the limestone is thought to cross the Murray R. near Carwarp. The Duddo Limestone may well be continuous with the Gambier Limestone in the south near the junction of the Murray and Otway basins; the time ranges of these two limestone formations overlap (Ludbrook 1964, Fig. 1).

The Duddo Limestone is thickest in the far W. part of the Mallee Region, thickening from about 300 ft in the far south to 600 ft in the Olney No. 1 bore. Throughout most of its extent it displays a regional dip towards the NW. corner of Victoria, but this regional dip is reversed in the Murrayville district where movement on the Danyo Fault has resulted in a monoclinal flexure, the Duddo Limestone there dipping to the south-east.

The stratigraphic relationship of the Duddo Limestone to the confining strata, although known to vary from one locality to another within the Murray Basin, is consistent within the Mallee Region, where it rests conformably on the Netherby Marl and is in turn overlain conformably or with possible disconformity in places by the Bookpurnong Beds. The upper boundary of the Duddo Limestone is always a sharp and easily discernible change downwards from greenish to grey clays and silts of the Bookpurnong Beds to the pale greyish-white Duddo Limestone. The lower boundary of the Duddo Limestone is not always easily discernible because the change from limestone to marl is often gradational. Electric logs have proved to be of value in selecting the upper and lower boundaries of the Duddo Limestone, which has a more negative spontaneous potential and higher normal resistivity than for the confining strata.

The range of lithologies shown by the Duddo Limestone includes pure limestone to marly limestone and thin beds of marl, the limestone being fine-grained and varying from calciludite to calcarenite. Using the classification for limestones proposed by Folk (1959), the Duddo Limestone in the Mallee Region is generally a sparry biogenic calcirudite (biostparrudite) or a sparry biogenic calcarenite; sparry calcite cement composed of grains or crystals 10-60 μ in diameter is common in the limestone. The biogenic constituents consist of the calcareous remains of bryozoans, foraminifers, echinoids, ostracodes, pelecypods, brachiopods, and scaphopods. The rock is highly permeable and porous and is a high yielding aquifer. In each vertical section there are always several thin and hard, but apparently uncorrelatable, bands in which the calcareous fossil remains are bonded together with calcareous cement. In places thin beds of chert nodules are found; in others there are non-calcareous sands, silts, and clays, but, except for the clays, these are usually insignificant.

From the fossil assemblage of the Duddo Limestone it is possible to determine the conditions of the marine environment in which this formation was deposited.

Bryozoa, the dominant fossil group present, are mainly cellariiform, indicative of offshore conditions; associated eschariform Bryozoa indicate depths greater than 60 ft (Stach 1936, Cheetham 1963). Still-living bryozoan species found fossil in the Duddo Limestone indicate that the water of the Murravian Gulf at the time of limestone deposition was of normal salinity, and that the climate was probably temperate. Benthonic Foraminifera outnumber planktonic ones; this and the large number of echinoid spines are further evidence for neritic conditions.

Micropalaeontological examination of drilled sections of the Duddo Limestone in Victoria (Chapman 1916, Crespin 1946) has demonstrated the time equivalence of the Duddo Limestone to the combined time range of the three units (? members) discriminated in South Australia: Pata Limestone, Morgan Limestone, and Mannum Formation.

WINNAMBOOL FORMATION—

East from the Duddo Limestone are contemporaneous marine calcareous sediments of variable lithology, here referred to as the Winnambool Formation. This rock unit is named after the gazetted township of Winnambool, 31 miles S. of Robinvale; it is near here that the type bore section, Geera No. 1, is located.

In this bore the Winnambool Formation was encountered between 340 and 490 ft, a thickness of 150 ft. The lithology ranges from a medium to light grey, marly clay to marl, in which gastropods and pelecypods are common, bryozoan skeletons rare, and glauconite grains common. The lithology at the type section is more uniform than in most other bore sections; elsewhere it includes clays, silts, marls, and some thin beds of limestone; there is often sufficient glauconite present to impart an olive grey shade to the sediment.

Our knowledge of the Winnambool Formation is sparse; private bores sunk for groundwater have only partially penetrated it because of the highly saline groundwater it contains; relatively few official bores have been sunk through it to bedrock. At each of these latter sites the Winnambool Formation rests conformably on the darker, and far less calcareous Geera Clay. This boundary is arbitarily selected at the change in depth from fossiliferous calcareous sediments to persistent relatively fossiliferous non-calcareous sediments. The fossiliferous dark grey to dark green and usually silty clays of the Bookpurnong Beds rests, probably conformably, on the Winnambool Formation throughout much of its distribution.

Despite meagre knowledge, the Winnambool Formation is thought to cover a broad arc, extending from S. of Hopetoun through Tempy and Piangil into New South Wales. Towards the east it lenses out, thus grading into the Geera Clay both laterally and vertically.

Micropalaeontological evidence shows that the Winnambool Formation ranges from the Longfordian Stage probably up to and including the Balcombian Stage. From its regional relationships, its significant proportion of terrigenous material, and its shallow water fauna of pelecypods, gastropods, and echinoids, the environment of deposition of the Winnambool Formation is regarded as inner neritic.

BOOKPURNONG BEDS—

The Bookpurnong Beds were defined by Ludbrook (1957) as red and green micaceous and glauconitic marls. They are typically exposed in the bank of the Murray R., 2½ miles downstream from Loxton, adjacent to section 11, 100 of Pyap (S.A.). A drainage bore near Loxton, on section 377, 100 of Gordon, provides the standard subsurface section. In the South Australian portion of the Murray Basin the Bookpurnong Beds disconformably overlie the 'Pata Limestone

Member' of the Duddo Limestone and, in turn, are disconformably overlain by the Loxton Sands. The Bookpurnong Beds were assigned by Ludbrook (1964), on the evidence of Mollusca and Foraminifera, to the Kalimnan and Cheltehamian Stages, i.e. Upper Miocene to Lower Pliocene.

Sediments similar to the Bookpurnong Beds as defined by Ludbrook (1957), yet showing certain deviations in lithology and age from that of the original definition, occur in the Mallee Region. The sense in which the term Bookpurnong Beds is used here is broadened to accommodate the Victorian variations of this unit. Throughout the Mallee Region they consist of a dark glauconitic and calcareous or clayey silt containing carbonate—usually as tests of Mollusca, Foraminifera, and Ostracoda. Biotite is often present, and in places there are stages of its alteration to glauconite which, in turn, may be oxidized to limonite or ferruginous clay; pyrite is rarely present. The Bookpurnong Beds form an almost continuous unit throughout most of the Mallee Region, but they are absent from the most E. part. The formation is thinnest to the south, in the S. half of the county of Weeah, where it probably persists over several thousand square miles as a 5 to 10 ft thick clayey unit. Northward there is a marked increase in the thickness, e.g. in the Yatpool No. 1 bore it is 235 ft thick and in the Olney No. 1 bore it is 212 ft thick.

The Bookpurnong Beds conformably overlie the Duddo Limestone and the Winnambool Formation except for possible disconformities towards the S. margin of the Murray Basin. This contact is generally distinct, although towards the east the underlying Winnambool Formation becomes more clayey and glauconitic, approaching the Bookpurnong Beds in character.

The time-range of the Bookpurnong Beds is related to some extent to its thickness. Where the Bookpurnong Beds are thin (as in the Warraquil No. 1 bore, situated at Netherby S. of the Mallee Region), the microfauna suggests correlation with the Cheltenhamian stage alone, but where the Bookpurnong Beds are thicker the microfaunal evidence suggests correlation with the Kalimnan, Mitchellian, Cheltenhamian stages and sometimes with the Bairnsdalian stage as well. In South Australia, Ludbrook (1957) correlated the Bookpurnong Beds on foraminiferal and molluscan evidence with the Kalimnan and Cheltenhamian stages. Accordingly, if the Bookpurnong Beds are considered on a regional scale, both its upper and lower boundaries are diachronous, with the formation as a whole being progressively older eastward.

The presence of *Elphidium* sp. and Miliolidae, the fact that it is the last regionally persistent fossiliferous marine formation in the Victorian portion of the Murray Basin, its high proportion of terrigenous material, and its diacroneity all suggest that the Bookpurnong Beds are offlap deposits from the upper neritic to littoral zones of the slowly retreating seas of the Murravian Gulf.

Diapur Sandstone—

The Diapur Sandstone, named after the township of Diapur in the Wimmera Region, is typically exposed in a railway cutting 2 miles W. of that township. It refers to the clastic regressive part of the Tertiary sequence of the Murray Basin in Victoria. This formation is similar to the Loxton Sands which were defined as 'cross-bedded, coarse, gritty, micaceous sands with shelly bands' (Ludbrook 1957), but differences of lithology and fossil content warrant their separation. The Diapur Sandstone is almost entirely fine to medium-grained sand, slightly micaceous, and unfossiliferous; strong cross-bedding is unknown. The Diapur Sandstone forms long, prominent topographic ridges, which are not apparent in the Loxton Sands. The junction of the Diapur Sandstone and the Loxton Sands, both considered to be facies variants of the one continuous regressive sequence, is thought to lie somewhere in the South Australian portion of the Murray Basin.

The foregoing discussion of the Diapur Sandstone has been largely based on bore-hole data for it is exposed in only a few isolated localities either at blowouts or as cliffs (up to 30 ft high at Red Bluff and Concertina Rocks in the Big Desert), in quarries, as at Nyah.

The lithology of the Diapur Sandstone is remarkably uniform. Mechanical analyses of outcrops show it to be fairly well-sorted, fine to medium-grained, and the proportion of clay usually less than 15% except towards the base where this proportion is usually higher. Quartz predominates, though there is some felspar and generally about 2% by weight of heavy minerals including limonite-coated quartz grains, zircon, and tourmaline. The uppermost 10 to 50 ft of the Diapur Sandstone

Fig. 6—Structure contours of the base and the position of the main ridges of the Diapur Sandstone in the Mallee Region. Note, this formation is absent in the SE. corner.

is cemented with limonite imparting a light brown to moderate reddish brown colour; cementation by silica is rare. Generally there is a zone at the top where the limonite has a pisolitic form, but the formation becomes mottled beneath this, the proportion of reddish-brown mottles decreasing with depth; the intergranular interstices are rarely completely filled.

The mobilization of iron and its concentration in the upper part of the Diapur Sandstone is attributed to post-depositional weathering processes. In fact, the profile is at times similar to a lateritic profile (*sensu lato*). The silicified sandstone, known variously as duricrust (Woolnough 1928), silerete and 'grey billy', found at Rock Holes in the Sunset Desert and common in the SW. part of the New South Wales portion of the Murray Basin, has already been attributed a similar origin to that of laterites (Northcote 1951).

Near the S. margin of the basin the lateritized horizon developed on the Diapur Sandstone rises up into the Dundas Highlands where it is developed on the 'tableland' deposits. It is generally held that the time of laterization was Pliocene, but there is evidence of its partial development on Quaternary alluvial members in the Northern Plains. This suggests that 'laterization' in Victoria, although apparently active in Upper Pliocene times, continued intermittently into the Quaternary.

Beneath the limonite cemented surface of the Diapur Sandstone, there is very little to no limonitic cement to bind the quartz grains together; the formation is then represented by loose sand. This sand is yellow to reddish-brown in colour for depths ranging from 50 to 250 ft, below which depth the colour changes to greyish shades. This colour change corresponds to the level of the main water-table, and is due to the change from reduced iron compounds in the saturated zone below the water-table to oxidized iron above. Another contributing factor to the colour change may be the increasing proportion with depth of the clay-silt fraction in the Diapur Sandstone.

The depth to the water-tables shows up clearly on electric logs by a marked decrease from the very high normal resistivity opposite the oxidized and unsaturated zone of the Diapur Sandstone to much lower normal resistivity opposite the water-table and its associated capillary zone.

The configuration of the Diapur Sandstone differs from the other Tertiary units of the Murray Basin sequence in that although it generally thickens from the S. margin of the basin towards the NW. corner of Victoria, its upper surface is moulded into a series of ridges. These ridges are up to several miles wide and up to 200 ft high, with these two dimensions directly proportional to one another; their profile may be either simple and approximately symmetrical, or complex. For the Victorian portion of the Murray Basin, the ridges of Diapur Sandstone are sub-parallel and generally trend in a NNW.-SSE. direction (Hills 1939). The main ridges forming prominent features on the surface are: one ridge consisting of three aligned segments trending NW. from Galaquil in the south, through Patchewollock to Meringur in the north; the Tyrrell Ridge extending from Watchupga in the south to Robinvale in the north (the easternmost of these ridges in the Mallee Region); and the Cannie Ridge which extends northward from Cannie into the Woorinen district (Fig. 6 and 7).

Data from bores sited on and beside the ridges of Diapur Sandstone at Walpeup (Mallee Region), Kaniva, Nhill (Wimmera Region) and Goroke (Glenelg Region) demonstrate that the configuration of the lower surface is independent of that of the upper surface. Structure contours drawn for the lower surface of the Diapur Sandstone in Fig. 6 show that this surface generally slopes towards the Hattah district, where in the Mournpoull No. 1 bore it was encountered at 214 ft below sea level. As suggested by Hills (1939) tectonism has had some effect on this surface. Uplift in the counties of Albert and Alfred in South Australia (Howchin 1929), and uplift in association with the Danyo Fault has resulted in an easterly-directed dip for the lower surface of the Diapur Sandstone in the W. portion of the Mallee Region. Moreover, there appears to be a N.-S. anticlinal structure within the Diapur Sandstone S. of Robinvale, where the lower surface of the sandstone dips to the west and to the east away from this line.

The Diapur Sandstone rests apparently conformably on the Bookpurnong Beds. The boundary is taken at the change from grey, unfossiliferous sands and silts of the Diapur Sandstone downwards to grey to olive grey, fossiliferous glauconitic clays and silty clays of the Bookpurnong Beds. The one known exception is in the Murraville-Pinnaroo district where the sands immediately above the Bookpurnong Beds contain marine calcareous fossils; these sands are tentatively correlated with the Loxton Sands.

Blackburn (1962a) suggested that 'the ridges represent dunes established at successive coastlines of the former Murravian Gulf'; he substantiated this claim with evidence that size-grading of the sandstone from the ridges is suggestive of an aeolian origin, and that all the ridges have sub-parallel alignment yet show terminal curvature near the Central Highlands and the several monadnocks of Palaeozoic rocks. The 'stranded coastal dune' hypothesis is supported, in my opinion, by bore-hole data revealing that the Diapur Sandstone immediately overlies Tertiary fossiliferous marine sediments. The Northern Plains lack both the Diapur Sandstone and Tertiary marine fossiliferous sediments. Their close association elsewhere is taken to indicate some sort of genetic relationship. Nevertheless, there are difficulties with this theory. There are no fossils known in the Diapur Sandstone, yet such material would be expected. The stranded Pleistocene coastal dunes in the Otway Basin are composed of calcareous aeolianite, the comminuted calcareous material having been derived from the remains of marine animals. But the lack of fossils, lime, or primary aeolian structures in the Diapur Sandstone may not preclude a dune origin because:

(a) Fossils would be expected to be scarce under conditions of rapid deposition and varying salinity
(b) Calcareous material deposited would be comminuted owing to deposition in such an environment; therefore, it would be more readily leached out by groundwater.
(c) Most important, the subsequent lateritization or deep weathering would have leached out all carbonates and obliterated all structures initially based on carbonate material.

Blackburn's (1962a) explanation of the Diapur Sandstone ridges is not applicable to the origin of the entire vertical section of this formation, for though the lithology is uniform laterally, the grain size generally decreases in depth. This could be explained by the lower part of the Diapur Sandstone being deposited under off-shore to littoral conditions, and the upper material, forming the ridges, being shore-line deposits. The Diapur Sandstone and the Bookpurnong Beds, accordingly, would represent a well-developed regressive phase.

Because of lack of fossils, the Diapur Sandstone can be dated only by considering its stratigraphic relationship with dated rock units, confining it laterally and vertically. It is regarded as being in diachronous relationship with the underlying Bookpurnong Beds; at their easternmost extent these beds appear to have been deposited in the late Miocene times, but with the retreat of the seas there was the cessation of marine deposition in Lower Pliocene times in the far NW. part of the

Fig. 7—Surface contours of the Mallee Region.

Mallee Region and in adjacent South Australia. Disconformably overlying the Diapur Sandstone is the fluvio-lacustrine Blanchetown Clay and Bungunnia Limestone succeeded by the aeolian Woorinen Formation divided into a sequence of aeolian increments which are considered to have been deposited during dry and windy phases of the Quaternary climatic cycles. If this is correct, and due allowance is made for development of the lateritic profile, then the Diapur Sandstone is entirely pre-Quaternary, with deposition ceasing an appreciable time before the Pleistocene.

Wunghnu Group

The Wunghnu Group refers to the post-Knight Group fluviatile and lacustrine sediments of the Northern Plains and to similar sediments in the Murray Basin W. of the Northern Plains. It is named after the township of Wunghnu, where

Mundoona No. 1 bore, selected as the type sub-surface section, was drilled by the Mines Department in 1960 and was continued and completed in 1962.

The Wunghnu Group is a continuous unit throughout the Northern Plains except where broken by monadnocks of Palaeozoic rocks. West of the Northern Plains it occurs around the N. margin of the Central Highlands and as sediments filling stream valleys. It occurs along existing streams as the Coonambidgal Formation in the Mallee Region; it is widespread in the Towaninny-Wycheproof district, parts of the Swan Hill district, and as a broad belt trending SSE. from Birchip. The following driller's log of a private bore 4 miles S. of Wycheproof shows the diverse types of lithologies of the Wunghnu Group and gives an impression of its thickness:

	Lithologic Description	Depth (ft) from — to
Wunghnu Group	Clay	0 — 159
	Sandstone	159 — 171
	Clay	171 — 200
	Sand	200 — 240
Knight Group	Brown coal	240 — 330
	Sand	330 — 331
	Ligneous clay	331 — 340
	Sand, fine-grained	340 — 354
	Ligneous clay	354 — 388
	Sand, coarse-grained	388 — 413
	Silty clay	413 — 419
	Sand, coarse-grained	419 — 421
Bedrock	Decomposed granite	421 — 492
	Granite	492 — 512

The upper surface of the Wunghnu Group is generally flat except for minor rises and sinuous shallow depressions. The lower surface of the Wunghnu Group rests with apparent disconformity on the Knight Group over most of its extent, but close to the outcrop of Palaeozoic rocks at Wycheproof and Charlton the Knight Group is absent and the Wunghnu Group rests with angular unconformity on the Lower Palaeozoic rocks. The criterion used to discern the boundary between the Wunghnu Group and the Knight Group is the first sign in depth of persistent carbonaceous beds (see driller's log above).

The nature of the junction of the Wunghnu Group with the Diapur Sandstone is not clear because of lack of exposures. It is assumed that those units of the Wunghnu Group which are contemporary with the easternmost Diapur Sandstone intertongue with it. The main differences between these two units are that the Wunghnu Group is highly variable in lithology, is mottled throughout its entire section and has a flat upper surface, whereas the Diapur Sandstone has a relatively uniform lithology, lacks mottling below a depth of about 50 ft and forms topographic ridges.

It is difficult to surmise the time at which deposition of the Wunghnu Group began, for the few fossils found so far are not diagnostic of age. All that is known is that there is continuous facies relationship across the Northern Plains and the Mallee Region, and that the Wunghnu Group, therefore, probably includes fluviatile and lacustrine sediments of the same age as the Diapur Sandstone, Bookpurnong Beds, Winnambool Formation, and Geera Clay to the west. But to what extent time equivalents of these latter are represented cannot be ascertained.

Numerous paleosols within the Wunghnu Group itself indicate diastems apparently caused by a combination of shifting stream patterns, climatic changes, and tectonic movement.

Quaternary Aeolian Deposits

Lowan Sand—

The Lowan Sand is named after the county of Lowan where it is exposed over large areas. Widely spaced traverses show it to be a greyish-yellow, fine to medium-grained, siliceous sand with a high degree of sorting (most pronounced near the crest of the dunes), low kurtosis, and positive skewness. Quartz is the predominant mineral, usually more than 98% by weight; the quartz grains are characteristically frosted and of high sphericity; the most common accessory minerals are muscovite, zircon, and tourmaline.

In Victoria, the Lowan Sand is mainly localized as huge 'tongues' extending eastward from South Australia. Of these tongues, the N. two lie within the Mallee Region forming the Big Desert and the Sunset Desert (Fig. 8).

The Lowan Sand is blown into dunes, generally 15 to 30 ft high, displaying an irregular pattern; vegetation is scant, the sand continuing to move eastward under the influence of strong westerly winds. The instability of these dunes has prevented pronounced soil development, although in the swales there are signs of slight clay illuviation. Separating the dunes are swales and a few extensive sand plains. Because of the irregular topography of the Lowan Sand, its thickness varies considerably from a few feet, to probably about 100 ft for some of the largest dunes. The upper surface of the Diapur Sandstone, where the Lowan Sand rests disconformably, has much more subdued topography than where buried by the Woorinen Formation. This is considered to be due to the more extensive deflation within the 'Deserts', where the Lowan Sand occurs, than outside them.

The source of the Lowan Sand has been variously attributed. Crocker (1946) concluded that what is here termed the Lowan Sand is the re-sorted quartzose A horizon of former dunes of the Bridgewater Formation stripped by wind during an arid period. Sprigg (1952, 1959) found a progressive decrease northward in the lime concentration and a complementary increase in the quartz content of the dunes of the Bridgewater Formation. He suggests that the sand has been winnowed from the Bridgewater Formation and has migrated eastward under the influence of strong winds. However, reconnaissance mapping of the Lowan Sand has not revealed significant regional variation of grain size or shape (confirmed by Blackburn pers. comm.) that would support Crocker's and Sprigg's suggestion for the origin of the Lowan Sand.

Hills (1939) was of the opinion that the Lowan Sand is the erosive product of the Diapur Sandstone. This conclusion is substantiated by the similarity of the Lowan Sand, texturally and mineralogically, to the Diapur Sandstone. Furthermore, the Lowan Sand is always closely associated with the Diapur Sandstone both within and outside the 'Deserts'.

The age of the Lowan Sand is considered to cover most of the Quaternary period. It is considered that during Quaternary times, climatic conditions become conducive to the breakdown of the Diapur Sandstone, and that this process, combined with migration of the dunes, has continued to the present.

The Lowan Sand, as defined here, does not include all outcropping loose sand in the Murray Basin, for there is frequently sand at the crests of the E.-W. dune chains that, in fact, belongs to the Piangil Member of the Woorinen Formation.

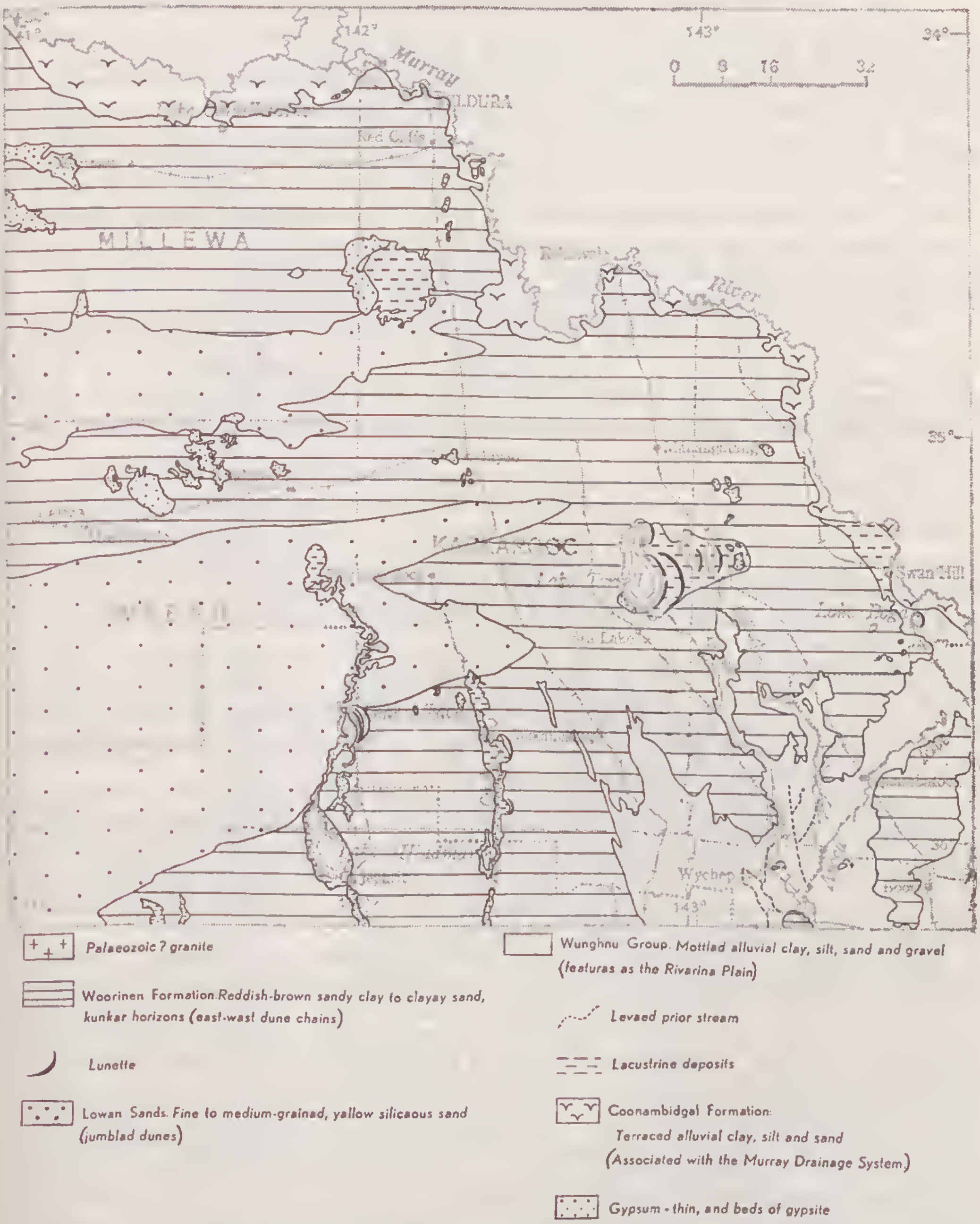

FIG. 8—Distribution of Quaternary rock-units in the Mallee Region.

WOORINEN FORMATION—

The aeolian landscape W. of the Riverine Plain, except for the Lowan Sand, consists of pale to dark reddish-brown, calcareous sandy clay and clayey sand in which at least five superimposed soils are present. The name proposed for these sediments is the Woorinen Formation, named after the township of Woorinen W. of Swan Hill; a low E.-W. trending dune in the N. part of allotment 8, section B, parish of Tyntynder is selected as the type locality; the choice is based on stratigraphic work by Churchward (1960). At this locality, hand-drilling into the dune has shown that the Woorinen Formation persists for more than 20 ft. Soil development on each aeolian layer leaves only thin zones of unweathered Woorinen Formation. In the Woorinen district, the unaltered zones are usually less than 2 ft thick; the shallowest of these lies at a depth of 4 to 5 ft. The unaltered material consists of calcareous sandy clay resting disconformably on earlier soils.

The upper surface of the Woorinen Formation is moulded by wind into various forms; the most widespread and characteristic of these are the E.-W. dune chains which consist of aligned unit dunes, typically several hundred feet wide, 10 to 50 chains long, and 10 to 30 ft high. In profile they are asymmetrical, with the S. slope steeper than the N. slope. The distance between dune chains generally ranges from 10 to 80 chains.

Although the dune chains almost certainly formed parallel to, rather than transverse to the dominant wind directions, they cannot be classed as typical longitudinal dunes. They are close, in fact, to Bagnold's (1960) 'tear-drop' longitudinal dune chains, which he thought to be due to winds shifting in direction by more than 90°. The dunes in the Mallee Region have formed under the influence of winds with a westerly vector; under the present wind regimen the dunes of Lowan Sand are moving eastward.

The shape and frequency of the dune chains in the Mallee Region are variable. In the far NW. the dunes are prominent and separated by narrow swales, but to the SW. the dunes are much more subdued in form and are separated by broad swales. E.g., in the Waitchie-Ultima district the dunes are low, elliptical to circular hummocks; near Brim the Woorinen Formation is a featureless sheet.

Throughout much of its distribution within the Mallee Region, the Woorinen Formation rests disconformably on the Blanchetown Clay or Bungunnia Limestone; where these are missing it rests disconformably on the 'lateritized' surface of the Diapur Sandstone. The topography is a composite of the closely spaced parallel E.-W. Woorinen Formation dune chains and the more irregularly spaced NNW.-SSE.-trending ridges of the buried Diapur Sandstone.

Churchward (1960, 1961a, 1961b, 1963a, 1963b), on pedological criteria, provided a rational means of differentiation of the Woorinen Formation into members. Hills (1939) had previously suggested that the lime rich bands in the dunes represented illuvial soil horizons and that the intervening layers of relatively non-calcareous, siliceous material were eluviated horizons. He further postulated that a series of arid periods contributed to dune formation and that these periods alternated with those of more humid conditions during which soils were developed. This interpretation has been endorsed by Butler (1956, 1958, 1959), and later by Churchward (1960, 1961a, 1961b, 1963a, 1963b) who has recognized five superposed aeolian accumulations disconformable to one another in the E.-W. dunes to the NW. of Swan Hill. Churchward named these aeolian layers, in order of increasing age; the Piangil, Kyalite, Speewa, Bymue, and Tooleybuc layers. These layers are referred to in this paper as formal members of the Woorinen Formation. Churchward's names have been adopted for these members except for the Tooleybuc layer;

this is here termed the Miralie Member because the name 'Tooleybuc' has been used already for a stratigraphic unit elsewhere in Australia.

Each of the members of the Woorinen Formation is parallel or sub-parallel to the ground surface. The crest of any member is characteristically displaced to the east and south of the crest of the next oldest member. This skewed relationship of members within a dune is most pronounced in the W. part of the Mallee Region where erosional truncation of one or several members, especially on the N. and W. slopes of dunes, has exposed the limey B horizons, variously known as calcrete, kunkar, caliche, or travertine.

MIRALIE MEMBER—

Named after the township of Miralie in N. Victoria, the Miralie Member is synonymous with the Tooleybuc layer of Churchward (loc. cit.), a name pre-occupied for stratigraphic use. It appears to be derived from similar parent material to the younger members, but is more deeply weathered.

BYMUE MEMBER—

The Bymue Member is a weathered calcareous, clayey-sand stratum buried disconformably below the Speewa Member. It is named after the parish of Bymue in New South Wales; it occurs typically at the crest of an E.-W. dune, 8 miles NE. of Tooleybuc Village (N.S.W.) where it is buried disconformably beneath the 22-in. thick Kyalite Member, no Speewa Member being present there.

SPEEWA MEMBER—

The Speewa Member is a calcareous clayey sand, named after the township of Speewa, N.S.W., where it occurs at the type locality of the Kyalite Member, but buried beneath it in the same dune; it outcrops in the swales adjacent to this dune. Where it is weathered, mobilization of the calcareous and clayey constituents by pedogenic processes has caused marked profile differentiation. It is known from field observations to contain a larger proportion of sand in the far NW. part of the Mallee Region than in the SE. part. Churchward (1963a) demonstrated that the Speewa Member in the swales NW. of Swan Hill is bimodal with maxima coinciding with very fine-grained sand and medium-grained sand, whereas at the crests of the dunes it is unimodal, being mainly coarse-grained sand. Unlike the younger Piangil and Kyalite Members, the Speewa Member persists across the swales, where it usually outcrops. It also outcrops in the SE. part of the Mallee Region where the Woorinen Formation has a hummocky form.

The thickness of the Speewa Member varies; it is thickest on the E. and S. slopes of dunes and hummocks where it may be 10 ft thick; it is thinnest on N. and W. slopes exposed to wind erosion. Often on N. and W. slopes of E.-W. dunes, particularly in far NW. Victoria, erosion has exposed the lime-enriched B horizon.

Soil development on the Speewa Member is considerable; the degree of soil development varies, being greatest in the far NW. part of the State. The variation in soil development is thought to have been mainly influenced by the permeability of the Speewa Member; this is higher in the W. part of the Mallee Region, where it becomes coarser-grained. Churchward (1963b) indicates that for the Swan Hill district, lime has been leached from at least the top 14 in.; the clay maximum there is at a depth of more than 9 in. and is associated with pedal development.

The Kyalite Member, named after the Kyalite (Edward) R. in New South Wales, is a brownish to reddish-brown, sometimes greyish brown, calcareous clayey

KYALITE MEMBER—

sand forming an asymmetric capping to the E.-W. dunes and associated hummocks. Its type locality occurs on an E.-W. dune near the S. boundaries of allotments 33, 34, 35, and 36, parish of Tyntynder. The Kyalite Member disconformably underlies the Piangil sand; it rests disconformably on the weathered Speewa Member, except where erosion has truncated this member. The thickness of the Kyalite Member varies; in railway and road cuttings in the Victorian portion of the Murray Basin it is seen to be usually 1 to 13 ft thick, but Churchward (1963a) found in the Woorinen district that it ranged up to 5 ft thick and was thickest on the S. and the E. slopes of dunes.

Insufficient mechanical analyses of the Kyalite Member prevent comment on regional textural trends, but within each dune profile of the member there is a characteristic pattern in grain size. In the dunes to the NW. of Swan Hill, e.g. the median grain size grades from very fine sand in the swales up to medium-grained sand at the crest of the dunes (Churchward 1963a).

The differentiation of the soil profile is only slight; lime has been leached from the top few inches, the clay maximum is at a depth of about 3 in., and there is no pedal development (Churchward loc. cit.). The Kyalite Member, unlike older members, is relatively homogeneous, owing to this limited soil development; lime cement binds the member togther. The lime occurs as hollow tubules, pseudomorphic after roots and rootlets, which have since decayed.

PIANGIL MEMBER—

The Piangil Member, named after the township of Piangil, is the youngest member, and consists of loose yellowish-orange sand. Its type locality is at the crest of an E.-W. dune, 1 mile NW. of Piangil township in allotment 142, parish of Piangil. It occurs typically at the crests of dunes and has built up against such obstacles as vegetation, fences, and buildings. Due to truncation by erosion it probably rests on all members of the Woorinen Formation, though it most commonly rests on the Kyalite Member. It is typically less than 5 ft in thickness but probably exceeds 40 ft in places. It shows no soil development, but primary structures including cross-bedding are present.

SOIL DEVELOPMENT ON MEMBERS OF THE WOORINEN FORMATION

The members of the Woorinen Formation are similar in lithology and form; their recognition requires knowledge of their vertical relationships to other members and, most important, their degree of soil differentiation. The discussion below refers to the far E. part of the Mallee Region where the Woorinen Formation is more clayey than elsewhere. Here, Churchward (1960, 1961, 1963a, 1963b, 1963c) has described both outcropping and buried soils in detail; the following remarks are largely a synthesis of his work.

Soil profiles are developed on all members except the Piangil Member, obliterating depositional bedding and texture. Several trends of profile differentiation have occurred to varying degrees. The calcite, which was originally dispersed throughout each member, has been mobilized and leached down the profile to give a lime pan or concretionary calcite horizon of kunkar; the oldest horizons, naturally enough, have been most affected by this process. Clay mobilization and soil structure development follow the same trend.

Because the degree of soil development increases directly with the age of the member in which it is developed, Churchward (1963b) concluded that the relative durations of the soil-forming periods were Miralie > Bymue > Speewa > Kyalite. Other factors, however, have influenced soil differentiation. Because of the thinness of members, weathering may be a cumulative process whereby there is continued mobilization of elements and re-organization of structure of buried members owing to the movement through them of groundwater.

Correlation of the aeolian sequences of the Mallee Region with the Quaternary time scale requires several assumptions. Firstly, it is assumed that the Quaternary climatic cycles of the Northern and Southern Hemispheres were in phase. It is further assumed that these cycles have some expression in the regional stratigraphy; this influence has been the subject of controversy. The lime present in the Woorinen Formation is considered by Crocker (1946) to have been wind winnowed from the calcareous aeolianitic Bridgewater Formation under the influence of strong westerly winds. If the genetic relationship between the Bridgewater Formation and the Woorinen Formation is correct, then dating of the Bridgewater Formation would enable dating of the Woorinen Formation; but this genetic relationship remains to be proved. Some workers are of the opinion that the stranded coastal dunes of the Bridgewater Formation formed during interglacials, whereas others consider them to have formed during glacials.

Butler (1956) has applied the lithogenetic term 'parna' to aeolian clay present in the Widgelli Member in the Riverine Plains to distinguish it from loess, which in the strict sense must be regarded as silt-sized wind-blown material. The parna is considered to be derived by deflation of soils during the unstable phase of the K cycle of Butler (1959); these unstable phases alternated with stable phases during which soils were developed, the stable phase being correlated with humid conditions and the unstable phase with arid conditions. Movement of dust continues to act to a minor degree at the present time, having been accelerated by human activity. It is associated with strong turbulent wind flowing over the drier regions of inland Australia, with duststorms more prevalent during dry than wet years (Loewe 1943).

Perhaps the most feasible hypothesis concerning the Quaternary climates is that of migrating climatic belts. It is generally assumed (Keble 1947, Fairbridge & Teichert 1952) that during the glacial phases climatic belts migrated equatorwards, bringing temperate and wet (pluvial) conditions to lower latitudes.

Sprigg (1959, 1964) claims that the coastal dune system fossilized the low sea level coasts of the glacial phases and that, at this time, 'loessial lime' was carried inland and lunettes formed. He believes that, although the conditions were wetter during the glacial phases, the winds were stronger and came from the west. This, he claims, would account for the position of lunettes, their relation to lakes and the trend of E.-W. dunes. It is my opinion that these aeolian features could equally have been formed under a wind regimen identical with that presently operating.

Lunettes

Lunettes, or crescent-shaped dunes, border the E. side of existing lakes and ancestral lakes. In plan they are concave to the west; their height decreases from the centre towards their N. and S. ends; their windward slope (lake side) is usually steeper than the lee slope. Lunettes in the Mallee Region range in height from a few feet up to 100 ft, and in length from a few chains to about 15 miles. There may be only one lunette adjacent to a lake, e.g. alongside the ancestral lake at Pine Plains, or there may be a series of lunettes, e.g. alongside L. Albacutya where four lunettes are probably present. Where there is a series of lunettes they are generally sub-parallel with their radii converging to a common point. Lunettes up to 15 miles E. of the present E. shore of L. Tyrrell are interpreted as lunettes of a huge ancestral L. Tyrrell. L. Timboram and L. Walpole, and their associated gypsum flats, are accordingly regarded as reliet lakes occupying depressions between lunettes of the ancestral L. Tyrrell.

The lunettes consist of clay, silt, and sand; gypsum or calcium carbonate horizons may be present. The lunettes alongside L. Albacutya consist of sand, whereas those in the Kerang district consist of clay and fine-grained sand (Baldwin, Burvill, & Freedman 1939). Mature soils are developed on some of the main lunettes and in some, especially near the S. and N. ends of lakes, buried soils are present.

Contradictory explanations for the genesis of lunettes have been presented. Hills (1939, 1940) considers that, when the lake was full, atmospheric dust of regional origin was captured by spray droplets derived from the lake; this dust dropped to form the lunette. By contrast, Stephens & Crocker (1946) consider that lunettes are derived from material blown from the dry floor of the lake. In support of the 'full lake' theory, Hills (1939) reasons that it would be improbable for aeolian surface drift and saltation to produce the regular form of the lunette and further, that the material of the lake floor is so fine-grained that when the lake is dry, much of it would undoubtedly be lifted into the air by strong winds and carried to remote areas.

A cogent refutation of the 'full lake' theory for genesis of lunettes is presented by Stephens & Crocker (1946), who maintain that the sand of which some lunettes are composed is too coarse to be moved by saltation and probably was moved by surface creep. They also remark that clay dust is not composed of ultimate particles, but of aggregates which behave like sand grains in being transported by saltation and surface drift. Indeed, I have found that lunettes may contain laminated aggregates similar to the dry clay aggregates found on the lake floors. The presence of gypsite in these lunettes alongside the gypsum flats is regarded as additional evidence for lunette material being derived mainly from the depression's floor. In the L. Boga district there are very low lunettes alongside areas not covered by water but where the water-table is sufficiently shallow to lie within the capillary fringe. Under these conditions, salts may well have precipitated at the surface causing thinning of the vegetation, and thus allowing westerly winds to carry salts and clay aggregates eastward to build up a lunette.

Multiple lunettes are explained by recession of the old shore line; each lunette formed individually, the oldest being farthest from the lake and the youngest being the closest. Lake recession would be followed by encroachment of vegetation, which would help trap the moving material, thereby enhancing the rate of accumulation.

The stratigraphy of the lunettes is known only in a general way. Probably most prominent lunettes in the Mallee Region pre-date the earliest phases of the Coonambidgal Formation. This is shown for instance at Swan Hill where the ancestral Loddon evades a large lunette to flow around its S. end. Paleosols within lunettes are expected to provide the best means of correlating the stratigraphy of the lunettes with that of the Woorinen Formation, but at present the relation between the periods of lunette building and the development of the E.-W. dunes is not known. It is obvious, however, that the lunettes formed when the winds were dominantly westerly. Sprigg (1959) claims that the lunettes were deposited during humid phases when the winds were dominantly westerlies due to equatorwards migration of the anticyclonic belt. Climatic fluctuations, nevertheless, may have had little effect on lunette formation; the arrangement of multiple lunettes, for instance, suggests a progressive decrease in lake size with the climate becoming progressively drier since lunette formation began.

Quaternary Alluvial Deposits

Blanchetown Clay and Bungunnia Limestone—

Both the Blanchetown Clay and Bungunnia Limestone, defined by Firman (1965), are Pleistocene lacustrine deposits found in association with one another, and limited to the NW. part of the Mallee Region and adjacent South Australia on the downthrow side of the Murrayville monocline; they occur between the ridges of Diapur Sandstone, but not on them.

The Blanchetown Clay is a light grey to weak red clay to clayey sand in which crustacean fragments are rarely found. It rests disconformably on either the Diapur Sandstone or a lower unit of the Lowan Sand. Although usually less than 20 ft thick, it ranges up to a maximum thickness of 60 ft in the banks of the Murray R. at Red Cliffs. Resting conformably on the Blanchetown Clay is the less widespread, thin, bedded, dolomitic Bungunnia Limestone; carapaces of the ostracode *Cypris praenuncius* (identified Chapman 1936) and algal structures are common. The Bungunnia Limestone is overlain by part at least of the Woorinen Formation.

Wunghnu Group

The alluvial sediments found in the Mallee Region and widespread in the Wycheproof-Teddywaddy district were discussed earlier under the Tertiary part of the Wunghnu Group. This discussion was concerned with the broader aspects of subsurface data. The following discussion concentrates on the younger, and generally outcropping, Quaternary units of the Wunghnu Group.

Shepparton Formation—

The Shepparton Formation is proposed for those essentially alluvial sediments of the Murray Basin that are older than the Coonambidgal Formation; it forms part of the Wunghnu Group.

Named after the city of Shepparton, the Shepparton Formation is typically exposed nearby in the E. bank of the Goulburn R. near the S. boundary of allotment 59, parish of Kialla, where it is represented by over 30 ft of fine-grained alluvial sediments marked at the top by a soil overlain by the thin and discontinuous Widgelli Member. The sequence of fine-grained sediments is broken by two further paleosols, enabling a further subdivision into members: Kialla Member, Katandra Member, and Quiamong Member. The youngest member of the formation, the Mayrung Member, is absent from this section.

In Victoria, the Shepparton Formation is limited to the Northern Plains and the alluvial valleys of N.-flowing streams in the Central Highlands. It is rare in the E.-W. dune system, where it is invariably buried. The geomorphology of the Northern Plains is a reflection of the upper surface of the Shepparton Formation, which is in places buried beneath a veneer of a sixth member of this unit, the aeolian Widgelli Member.

The best known members of the Shepparton Formation are its shallowest and youngest members, the Quiamong and Mayrung Members; these deposits and facies variations have been described by Butler (1958). Older members are assumed to have been derived from similar streams despite the absence of known levee deposits associated with them. The prior stream deposits consist mainly of clays and silty clays, but there are also sands and rare gravels. The sands may extend through the whole vertical section of the prior stream deposits, or they may occur as a thin extensive sheet at their base, grading upward into finer material.

These prior stream deposits doubtless had a similar provenance to the Recent deposits of existing streams, the former and present drainage regimes having essentially the same catchments on fine-grained Palaeozoic sediments, metasediments and granites of the Central Highlands, blanketed in places by late Pliocene and Pleistocene basalt flows.

Like the existing streams, the prior streams, at least in their final and aggrading phase, displayed high sinuosity. Occasionally, the point bar pattern is visible at the surface, demonstrating that lateral migration of the stream helped to build up the deposits; but in general, overbank deposition seems to have been the most significant type of deposition, usually extending for several miles from the prior stream course in the cases of the observable Mayrung and Quimong Members, and obliterating the point bar pattern.

COONAMBIDGAL FORMATION—

The 'Coonambidgal', defined by Butler (1958), is here used for the first time as a formal formation name. Its type locality is outside the Mallee Region in the bank of the Coonambidgal Ck, near the NE. corner of lot 75, parish of Deniliquin, New South Wales. It is applied to the deposits of existing streams, or their recent ancestors, in the Murray Basin. It is clearly mappable as a floodplain with paired terraces alongside existing streams, some of whose dimensions are out of harmony with their present discharges. In the Mallee Region, incised streams have deposited these terraces below the level of the Woorinen Formation; the width of these terraces reaches several miles in the case of many cross-sections of the Murray R. The terrace surfaces frequently display scrolls and oxbow lakes, remnants of earlier meandering.

The Coonambidgal Formation is generally a slightly micaceous silty clay, but also includes clay, silt, sand, and gravel, either alone or as various admixtures; it is generally less than 60 ft thick. The degree of profile differentiation in soils of the Coonambidgal Formation is less than that occurring in soils of the Shepparton Formation. There are variations in soil type throughout the formation caused by variation in parent material and microtopography. Baldwin, Burvill, & Freedman (1939) described soils in the Kerang district which Pels (1964) later associated with an ancestral Coonambidgal Formation river channel along which Pyramid Ck now flows.

The Coonambidgal Formation is best known where it is associated with the Murray drainage system (Pels 1964). The existing Murray R. follows a relatively new course to Wakool Junction, but beyond this point it follows the course of the ancestral Murray R.; the present Wakool R. is an ancestral course of the Murray R. The Murray R., downstream from Wakool Junction, adopts the same meander pattern and channel width as the Wakool R.; immediately upstream from the junction it has a wavelength of about 15 chains, whereas downstream from the junction its wavelength is about 50 chains; downstream from the junction the Murray R. occupies a gorge incised into the Woorinen Formation and the underlying units. The alluvial deposits of this tract consist of two inset terraces and a narrow floodplain. Upstream from Wakool Junction the three Upper Pleistocene to Recent phases of activity of the Murray R. are not preserved in the one valley, but have been separated due to recurrent tectonic movement (Pels 1964) on the Cadell Fault (Harris 1938). Between Wentworth and the NW. corner of the State there is a huge terraced area of alluvial plains (terrace No. 2); this terrace will be drowned following construction of the Chowilla Dam in South Australia.

The sequence of terraces within the Coonambidgal Formation suggests periodic variation in discharge in response to climatic change. The above scheme implies three phases of degradation alternating with periods of aggradation, coinciding with variations in discharge during Upper Pleistocene to Recent times. Alternatively, there may be only two main phases represented by a floodplain (= terrace No. 1 + floodplain) and a major terrace.

The ancestral streams involved in the deposition of the Coonambidgal Formation are likened to the existing river courses (excluding anabranches). These streams are characterized by high sinuosity (in excess of 2), a high depth to width ratio, and approximately 45° banks. Taking the plain tract of the Murray R. as an example: its sinuosity is generally over 2, its depth to width ratio varies from 1 : 18 at Albury to 1 : 28 at Mildura; its bed slopes 9 in. per mile at Albury, decreasing to 3·8 in. per mile near the South Australian-Victorian border. The high depth to width ratio is explained by the inherent resistance of the clayey banks to scour, and the stabilizing effect of vegetation, principally redgum—*Eucalyptus camaldulensis*.

Evaporites

Recent evaporites are common in the Mallee Region but rarer away from it. The precipitation of evaporites is understandable as the average annual evaporation of 50 to 60 in. greatly exceeds the annual average rainfall of 10 to 14 in.; this achieves a main prerequisite, viz. potential loss of water by evaporation exceeding the rainfall; the process is further aided by movement of surface water and groundwater into the area.

Evaporites in the Mallee Region consist of calcium carbonate, halite, and gypsum. Except that some calcium carbonate can be present with earthy gypsum, each of these salts is usually found in geomorphically distinct situations:

(a) Calcium carbonate is concentrated in the paired levees of the prior streams of the Wycheproof-Towaninny district. It is thought to have been precipitated from stream water lost by influent seepage and is attributed partly to evaporation of capillary waters within the levees.

(b) Halite is precipitated in shallow lakes or salinas. These lakes may be fed by—

  (i) the internal surface drainage, e.g. L. Tyrrell and L. Timboram, respectively the terminal lakes of the Tyrrell and Lalbert Creeks, both effluents of the Avoca R., or

  (ii) almost entirely by groundwater, e.g. the Pink Lakes N. of Underbool, and L. Kunat near Swan Hill.

The salinas are occupied by saline water during most, if not all, of the year; wave action is responsible for a well-defined shore-line. Another conspicuous feature of the salinas is a lunette of sand or clay, or an admixture of both, situated along the eastern margin of the lake. Analyses of water from a number of salinas show a high amount of sodium and chloride, probably from cyclic salts, with lesser amount of magnesium, calcium, and sulphate. As the water evaporates, halite is precipitated almost exclusively, apart from minor amounts of calcium carbonate and gypsum. Cane (1962) has demonstrated for the Pink Lakes that the seasonal fluctuation of water level assists in draining away the magnesium-rich bitterns remaining after the halite has precipitated; this mechanism is believed to apply to the other salinas as well.

(c) Gypsum occurs in thin but extensive sheets or gypsum flats, believed to be the sites of ancestral lakes. There is generally only one gypsum bed beneath these flats, often extending from a depth of about 1 to 4 ft, but in the Cowangie district gypsum is found at depths as great as 20 ft, with several gypsum beds separated by sandy clay. The largest gypsum flats occur south of Meringur, at Nypo, at Raak Plain W. of Hattah and Nowingi, and at Kow Plain near Cowangie (Fig. 8). They are characteristically marked by an expanse of dry grey mud covered by an efflorescence of evaporite salts and a growth of samphire—*Crithmum maritimum*. Low winding dunes composed of gypsite, variously known as earthy gypsum, flour gypsum, copi, or kopi, are sometimes present on the flats.

A section typical of a gypsum flat is shown by a bore sunk in allotment 8, Parish of Tutye:

	ft
Grey mud (possible clay-sized gypsum) and gypsite	0 — ½
Gypsite, white	½ — 6
Gypsite and selenite	6 — 10
Sandy clay, yellow	10

Water is unknown at the surface of the gypsum flats, except temporarily as a result of heavy rain; instead, the water-table lies several feet below the surface. The gypsum is a chemical precipitate from saline groundwater. The water apparently rises due to capillary action precipitating the gypsum as coatings on existing crystals in the zone of aeration. During this process, which probably has continued for thousands of years, co-precipitation is slight and restricted to sodium chloride and calcium carbonate. An important key to the genesis of gypsum and salt is that, in those depressions in gypsum flats in which the water-table is intersected, salt is the major precipitate. This demonstrates that where water is exposed and entirely or almost entirely evaporated, sodium chloride predominates, but where the water-table is just below the surface there is fractional crystallization of calcium carbonate and gypsum with the other salts remaining in solution.

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Explanation of Plates

PLATE 53

Fig. 1—Exposures of Woorinen Formation derivatives, Bungunnia Limestone, Blanchetown Clay, and Diapur Sandstone along the cliffs of the Murray R. at Boundary Point, far NW. Victoria.
Fig. 2—Section through an E.-W. sand dune of the Woorinen Formation in a cutting of the Calder Highway at Hattah.
Fig. 3—Typical gypsum flat ('copi swamp') near Nowingi.
Fig. 4—Sand dune of the Lowan Sand, Big Desert.

PLATE 54

Vertical aerial photomosaic of the jumbled dune pattern of the Lowan Sand, adjoining the E.-W. dune system of the Woorinen Formation to the north and lacustrine deposits to the south (Wirrengren Plain) in the Big Desert, S. of Underbool. Scale—1 inch : 1 mile.

PLATE 55

Vertical aerial photomosaic of the gypsite deposits of the Raak Plain, and associated lacustrine and aeolian deposits, SW. of Nowingi. Scale as for Pl. 54.

PLATE 56

Vertical aerial photomosaic of the Coonambidgal Formation floodplain and terrace deposits associated with the Murray R., E. of Nowingi. Scale as for Pl. 54.

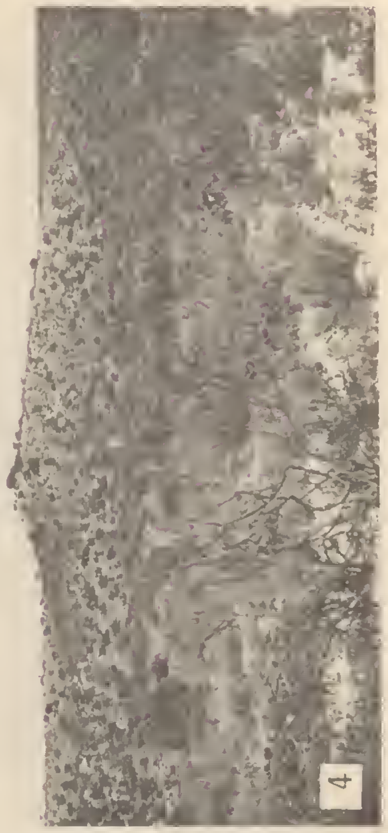
Addendum

While this paper was in press and just prior to receiving proofs, a geological map of the Pinnaroo-Karoonda area by J. B. Firman was published by the South Australian Geological Survey. Some rock units used there are equivalents of units used in the above text. The geological section accompanying the map lends further support to the synonymy of the Ettrick Formation with the Netherby Marl; the Parilla Sand is equivalent to the Diapur Sandstone; the Molineaux Sand corresponds to my use of the Lowan Sand plus the Piangil Member of the Woorinen Formation.

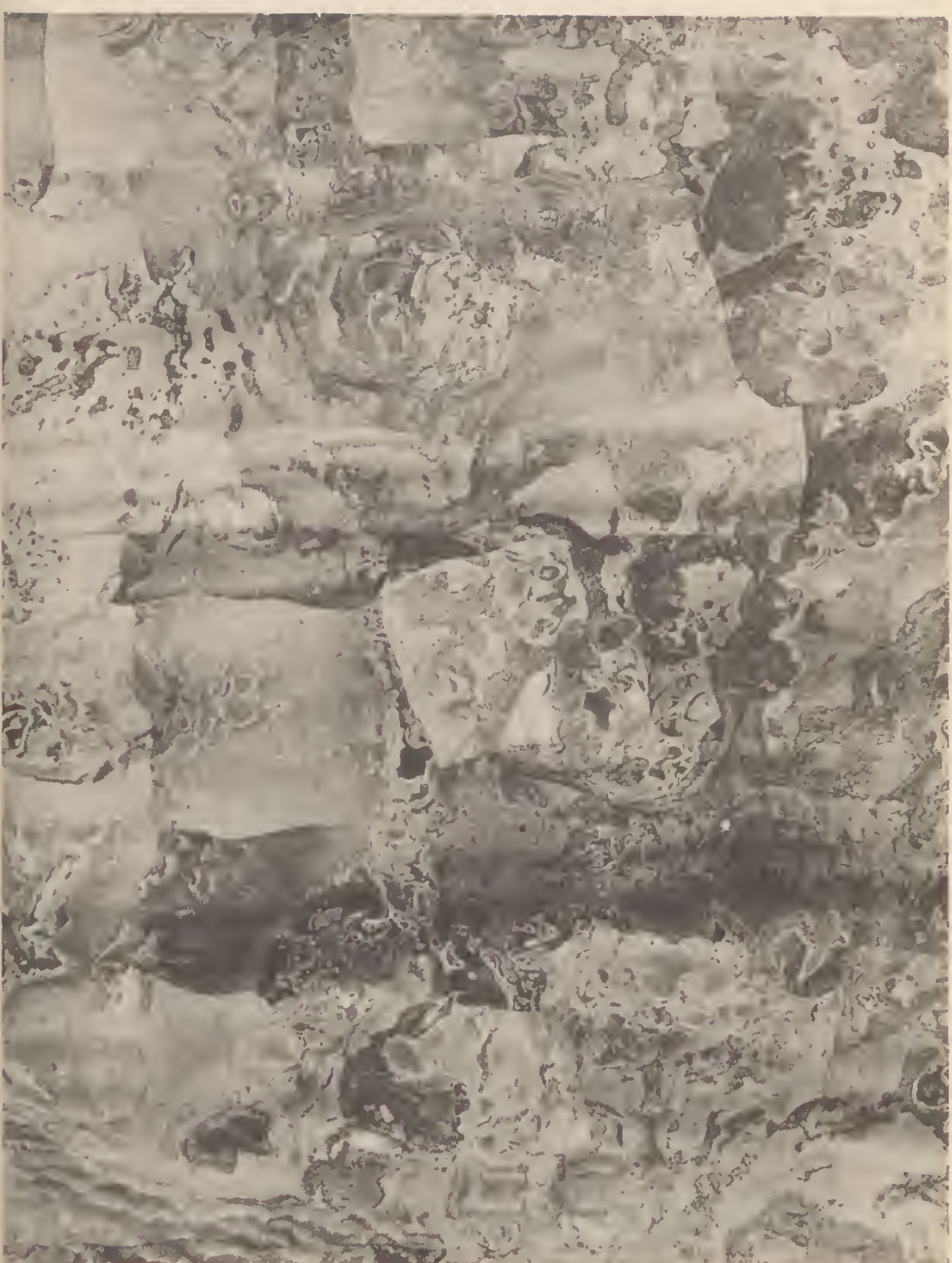
1

2

3



4




River
Creek
Murray
Cantala Creek
Chalka
LAKE
BITTERANG
LAKE
CANTALA

33

GEOCHRONOLOGY OF VICTORIAN MALLEE RIDGES

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Abstract

A tentative chronology for the Mallee ridges is proposed. Between the mid-Holocene parna dunes and the Upper Pliocene fluviatile deposits lie three generations of dunes. As these were dry-period structures, they may well belong to the Last Interglacial, the Penultimate Interglacial, and the Antepenultimate Interglacial respectively. The oldest dunes are eroded, cloggd with parna, and in places covered with a solid carbonate hardpan; it is easy to overlook them as former dunes.

Introduction

The marine formations underlying the Mallee have been described (Johns & Lawrence 1964, and references). Also the parna sheets and fluviatile deposits of the Murray riverine plain have been elucidated by Butler (1959 and references) and members of his organization (Churchward 1963, and references), and by University research workers such as Langford-Smith (1962). In all the above work some attention has been given to relative and chronometric dating. The writer has had the following scheme in mind for many years, and ventures it for dicussion on the occasion of the Symposium.

Mallee Ridges

The ridge morphology dominates the Mallee terrain. As a result any linear elevated area tends to be called a ridge. It should be frankly recognized that the term 'ridge' covers some four categories of structures, although some of these merge into one another, and may be superposed on one another.

1. Dune ridges, longitudinal and crescentic.
2. Depressed dune ridges.
3. Broad rises that might be called 'palimpsest ridges' because they are the faint remaining structures of what once were dunes.
4. Residual elevated areas that are outliers of ancient terrains of Tertiary age.

Relative Chronology

The above four categories are in order of relative age, and some of the evidence is as follows:

1. This category can be further divided into two, viz.:
   (a) The **white dunes** which are active now or have been in the recent past, as is shown by their sharp morphology, lack of compaction, and absence of obvious humus in the surficial sand. These are well developed, for example, in the Wyperfeld National Park. The sands are siliceous and they vary in colour from off-white to light fawn.
   (b) The **yellow dunes** are parna dunes bordering present and former lakes. Geomorphologically, they are commonly lunettes (Hills 1941), though many other shapes occur. Granulometrically they are silts and clays, being a fine fraction formerly accumulated on lake floors, then blown up as aggregates when the lakes were dry (Stephens & Crocker 1946; Gill 1953,

1964a, b). Having a structured soil developed on them, they must be older than uncompacted white dunes without a structured soil. Isotope datings will be quoted in support of this later in the paper.

2. The depressed dunes are **red dunes**, and consist essentially of siliceous sand. These are older than the yellow dunes, as would be expected from their depressed morphology and red earth soils. Near the town of Rainbow the relative ages of the yellow and red dunes can be demonstrated. The town stands on a crescentic red dune that gives the town its name by reason of its shape. Within the arc of this dune is a parna dune which, SW. of the town, partly truncates and partly overlies the edge of this dune. Thus, erosion followed the formation of the red dune before the yellow dune was emplaced. Therefore, the yellow dune is appreciably younger than the red.

The red dunes with marked carbonate accumulations in their soils are believed to be older than those without, so making possible a subdivision also of category 2, viz.:

(a) Red dunes without carbonate nodules (as at Rainbow).
(b) Red dunes with carbonate nodules.

3. The **palimpsest ridges** are so depressed morphologically that they probably would not be thought of as ridges elsewhere. Pre-occupation with accompanying ridges, and the necessity of finding routes for irrigation channels have drawn attention to them. The soils are grossly polygenetic. A solid hardpan of carbonate is common, and may be 2 or 3 ft thick. In areas where there is no hard-rock outcrop, it is used for road metal. In the early days it was used as a building stone (e.g. churches in Hopetoun still in use). The carbonate is the B horizon of a soil whose A horizon has been lost, while the present soil is developed on material gathered disconformably on the hardpan. The hardpan follows a depressed dune terrain, so the soil of which it is a relic was formed after both the establishment and erosion of the dune. So the original dune must be very old.

Some of these older dunes are clayey. In hand specimen they appear to be granulometrically bimodal, consisting of siliceous sand of dune-building range of size, and of a fine silt-clay fraction. With each dry Interglacial, the Mallee must have become a 'dust bowl', and the fine fraction of wind-eroded sediments dusted over the terrain. In the wet period that followed, much of this parna would be washed down into the sand dunes, thus making them clayey. The remainder would be washed into lake beds and stream channels to form a supply of parna for the next dry period. A thorough grain-size study of these cycles could be scientifically rewarding.

Just as the yellow parna dune overlies the red dune at Rainbow, so the red dune overlies the palimpsest ridge on which much of the town of Rainbow is situated. At the S. end of the town in the railway reserve on the E. side of the line there is a small quarry where the solid carbonate characteristic of these depressed ridges has been quarried. Cultivated fields in the area also show quantities of carbonate rubble. Thus, there are three superposed ridges at Rainbow providing proof of relative age. There is no red dune with carbonate nodules in this sequence.

4. No dune structures older than the palimpsest dunes have been recognized. No Upper Pliocene dunes are suspected. From what is known of the climatic conditions (Gill 1953, 1961a, b), they would not be expected in the area studied.

An important tectonic event affected the sedimentary processes of the Upper Pliocene and Lower Pleistocene (and to a lesser extent the times just before and just after that span)—the **Kosciusko Uplift**. This caused the Murray Basin to be drained, so that the latest marine formations under the Mallee are apparently Lower Pliocene. The uplift rejuvenated the river; it depressed some areas but raised others, and quickened sedimentation in the depressed areas. Some of the movements were small, but because continued over long distances they became significant. Up to 500 ft of non-marine sediments were deposited in the Mallee over the marine strata, and it is from these comparatively poorly sorted fluviatile seediments that the dune sands and parna have been extracted by winnowing. The sands are the saltatory fraction, and the parna the air-borne fraction.

As the E. half of the Mallee has no marine rocks under it, and as in the W. half the marine rocks are buried at depth, I cannot follow Blackburn's suggestion (1962) that the dunes are stranded marine shoreline structures. If they were, shallow water marine sandstone should pass up into beach sands, and they into dune sands as occurs in the postglacial, Last Interglacial and Penultimate Interglacial deposits in the Warrnambool-Port Fairy district (Gill 1966), and in the Lower Pleistocene (Werrikooian) at Devil's Den on the Glenelg R. (for locality see Fig. 10, Singleton 1941).

Hills (1939) suggested that faults in the bedrock account for some of the ridges; if so, the results are amazingly even considering the distance they extend, the irregularity of the bedrock, and the varying compaction of the Cainozoic sediments involved. Unless the displacements are recent, erosion would have obliterated them in view of the softness of the surficial sediments, and the instability of the terrain.

Red sandstone occurs in the cores of some of the dunes. This can be from Lower Pliocene lateritic profiles, Upper Pliocene rubifications, or remnants of Lower to Middle Pleistocene red dunes.

A section revealed in a quarry on the Swan Hill-Ultima road about two miles E. of Ultima is helpful. It occurs on the E. edge of a red dune at the commencement of a flat area. The succession is as follows (Munsell colours are for dry samples):

Surface 0″ — 1′ 8″	Dark red 2.5YR 3/6 structureless lightly compacted poorly sorted sand merging rapidly into
1′ 8″ — 3′	red 2.5YR 4/6 firm sandy clay to clayey sand, poorly sorted.
3′ — 6′	Compact mottled red and pale grey poorly sorted clayey sand (red 2.5YR 4/6 to 7.5YR 7/2 pinkish grey).
6′ — 8′ 6″	Very compact reddish yellow 7.5YR 6/6 poorly sorted sand, with bands of carbonate up to 1½″ thick.
8′ 6″ — 10′	Same but harder and including numerous nodules ½″-1″ in diameter, comonly oval in section, poorly sorted, brownish yellow 10YR 6/6. Thickness of this horizon varies from 2′-3′ thick. Orange bands 1″-2″ thick where iron oxide present.
10′ — 11′ 6″	Lightly compacted orange sand, with dark red iron-rich bands, forming an aquifer (Colours 10IR 6/6, 7.5YR 6/6, 10R 4/4).
11′ 6″ +	Light grey 5Y 7/1 fine poorly sorted sand. This horizon is at least six feet thick; the coarseness of the sand varies considerably.

I am indebted to Mr A. M. Gill for help in describing this section. The profound leaching and kaolinization of the sands in the bottom of the quarry are characteristic of the Nunawading Terrain (Gill 1964a), which has been traced from N. Tasmania to S. Queensland. It is also characteristic of the pallid zone of a laterite (Timboon Terrain), and to which of these terrains it belongs cannot be ascertained on present information. The Nunawading Terrain penetrates to as much as 150 ft, while the pallid zone of the laterite is not usually very thick. Rowan & Downes (1963, p. 17) refer to evidence of lateritization in the Mallee.

Absolute Dating

The relative ages of the various structures have been indicated, and their absolute ages may now be considered.

1. The parna dunes on the beaches of recent lakes are mid-Holocene in age as has been shown by radio-carbon dating, e.g. at L. Weeranganuck a lacustrine beach deposit with bones passes up into parna dunes. The bones gave a ^{14}C age of 6435 ± 110 years B.P. (Gill 1964b). The parna dune is therefore a little younger than this date.

2. The laterite (Timboon Terrain) in Victoria is of Lower Pliocene age, as is shown by marine fossils (Gill 1964a). At Grange Burn near Hamilton in W. Victoria, the waning effects of lateritization are impressed on the surface of a basalt (Gibbons & Gill 1964) which overlies an Upper Pliocene terrain developed over Lower Pliocene (Kalimnan) marine beds. The age of the basalt by potassium/argon dating is 4·35 mill. years (Turnbull, Lundelius, & McDougall 1965).

3. Non-marine sedimentation on the E. side of the Mallee area was synchronous with marine Lower Pliocene sedimentation on the W. side. Superimposed on both are Upper Pliocene non-marine beds.

4. The parna dunes represent a minor cycle, but each of the other types of dune ridge appears to represent a major cycle. They belong to drier periods, which in this area means Interglacials. If three Interglacials are involved, they must be the Last, the Penultimate, and the Antepenultimate. A tentative dating of the Mallee ridges is given in Table 1.

TABLE 1

HOLOCENE	Upper—White dunes (sand) Middle—Yellow dunes (parna)
PLEISTOCENE	Last Interglacial—Red dunes (? Penultimate Interglacial—Red dunes with carbonate nodules) Antepenultimate Interglacial—Palimpsest dunes with thick carbonate hard-pans
PLIOCENE Upper	Deposition of Kosciusko sediments (continued into the Pleistocene)
Lower	Deposition of marine (Kalimnan) beds in part of the area, and lateritization of the terrestrial part (Timboon Terrain)
MIOCENE	Nunawading Terrain formed. It is not known whether this terrain is represented in the Mallee.

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THE REGIME OF HATTAH LAKES

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Introduction

On the margins of the Mallee, about 40 miles S. of Mildura, lie the Hattah Lakes, a series of connected depressions which fill by flooding from the R. Murray, and sometimes spill over to adjacent areas. Most of the flood system is shown in Fig. 1. The southern chain of lakes lies within Hattah Lakes National Park but the remainder of the system is in the Kulkyne State Forest, now of little use for timber, some parts being grazed and small areas of sand dunes having completely lost their vegetation cover. Of an area about 14 miles square encompassing the whole flood system, approximately half is occupied by mallee associations and most of the remainder by floodplain associations of black box. The vegetation has been described by Patton (1930) and Zimmer (1937), and other characteristics of the floodplain have been presented by Tate (1885) and in a report by Rowan & Downes (1963, p. 103-105). The network of lakes may represent a former channel of the River Murray, and Hills has remarked upon the recent changes to the Murray's course which seem to have occurred in this area (Hills 1939, p. 317). Whatever the origin of the lakes, however, it is clear that the pattern of stable dunes, together with recently, and even currently, drifting sand, have exerted considerable influence on the present drainage pattern and the conformation of the lake basins.

In all, there are about 17 lakes which are connected with the R. Murray by Chalka Ck, an anabranch flowing about 11 miles from its inlet on the river to the lake system and a further 17 miles to its outlet. To reach the lakes, floodwater enters Chalka Ck at a rock bar across a bend in the river, about 100 miles upstream from Mildura. The bar (Pl. 57, fig. A), in low and moderate flows, confines the river to the inside of the bend but at high flows the body of water impinges on the outside of the bend and, if of sufficient depth, feeds a network of narrow, deep channels (Pl. 57, fig. B), uniting to form Chalka Ck. This effluent water, provided that the flow is high enough and lasts a sufficient time, fills the lakes in sequence and returns to the Murray by the northern channel of the creek, where it is ponded back by the flood peak on the river, after which the return flow is accelerated.

This flood system, until recently, constituted the only one in Victoria remaining completely unaltered and in its natural relationship with the river. During the 1964 flood an earth bank was completed between Lakes Hattah and Little Hattah, in order to retain more water in Hattah after the recession of the flood. This is only a minor modification to a part of the system but, before others are made which may destroy its uniqueness, it is important that as full a knowledge of the system as possible be obtained, in order to both manage the conservation of the area in its own right and to establish a basis for comparison with other flood areas so as to permit assessment of the effects of major artificial modifications. As Jennings

FIG. 1—Hattah Lakes. The map is drawn from aerial photographs to show the approximate maximum confined areas of each lake. Numbered arrows refer to the timing of the flow of water past various points, in days after water entered Chalka Ck in 1964. This information was supplied by E. McDonald.

(1965, p. 155) has pointed out, 'if all the land is modified, it will be impossible or at the least very much more difficult to discern any such effects'.

As a foundation for further studies the pattern of flooding and its frequency over the years were examined in order to establish the regime of the Hattah Lakes.

The Recorded Pattern and Sequence of Events

Since 1908, the Victorian Railways Department has kept monthly records of the depth of water in L. Hattah, the deepest of the lakes, from which water is pumped to the railway halt at Hattah, 2 miles away. These observations were supplemented, during the 1964 flood, by Mr Eric McDonald, the warden of the National Park, who made daily readings of the L. Hattah gauge and observed the wider extent of water in the flood system. Some of this information is shown in Fig. 1 as the progress of floodwater in the 1964 flood. In addition, lines of Red Gums and stranded debris mark the extent of some of the earlier major floods.

The recorded levels from previous floods are summarized in Fig. 2. This shows that in the 56 years of observations at L. Hattah, there have been 35 years when some inflow has occurred, a slightly better average than once every two years, and hence 21 years when there has been no replenishment of the lake. It is normally during the third dry season that the lake completely dries out, the surrounding country being already dry by that time. Two consecutive years of no inflow were recorded four times, in 1913-14, 1929-30, 1937-38, and 1940-41, and three consecutive years of no inflow were recorded twice, in 1943-45 and 1961-63. Over the same 56 years L. Hattah has been completely dry on seven occasions, the longest period being 21 months following the drought years 1943-45. The maximum depth of water observed in the lake was during the 1956 flood, when, following a particularly high flow on the Murray in 1955 a substantial body of water was already in the flood system. The gauge at that time could be read only to 18′ but levelling to well defined strand lines indicated that the water level rose to about 20′. Only 8′ were retained, however, by the closed basin, as in the case with all floods most of the remainder draining back to the Murray after the passage of the flood peak.

The observations made during the 1964 flood were compared with the earlier records, but lack of instrumentation, and the necessarily haphazard observation of some of the lakes lying well outside the park, limit the value of one season's detailed records. Nevertheless, some indicators of past flooding have been tentatively derived. For the southern chain of lakes, from L. Hattah to L. Nip Nip, to be filled by the water penetrating the system, the depth in L. Hattah must reach about 12′. This depth has been observed in 23 of the 35 years of inflow and, in most of the remaining floods, the maximum depth reached would ensure some water in perhaps all the southern lakes except Nip Nip. In 1964 this depth in L. Hattah was reached 26 days after the time water entered Chalka Ck, but the timing will clearly be affected by the amount of water already in the flood system. The lakes to the north fill later and when water entered L. Bittrang, the last of the major network to fill, L. Hattah had 13′ of water, this after 55 days in 1964. Fig. 2 shows that, in addition to the 12 years when the water level in L. Hattah did not even reach 12′, it is unlikely that L. Bitterang received water from 1931 to 1939.

When all the lakes are full, water gradually overflows to surrounding areas, including an intricate complex of sand dunes and box flats to the south-west of L. Lockie. When water overflowed into this area in 1964, L. Hattah had a depth of 13½′, 76 days after the inflow of water to the system. In the past, few floods have put this depth of water into L. Hattah and, from the available evidence, it

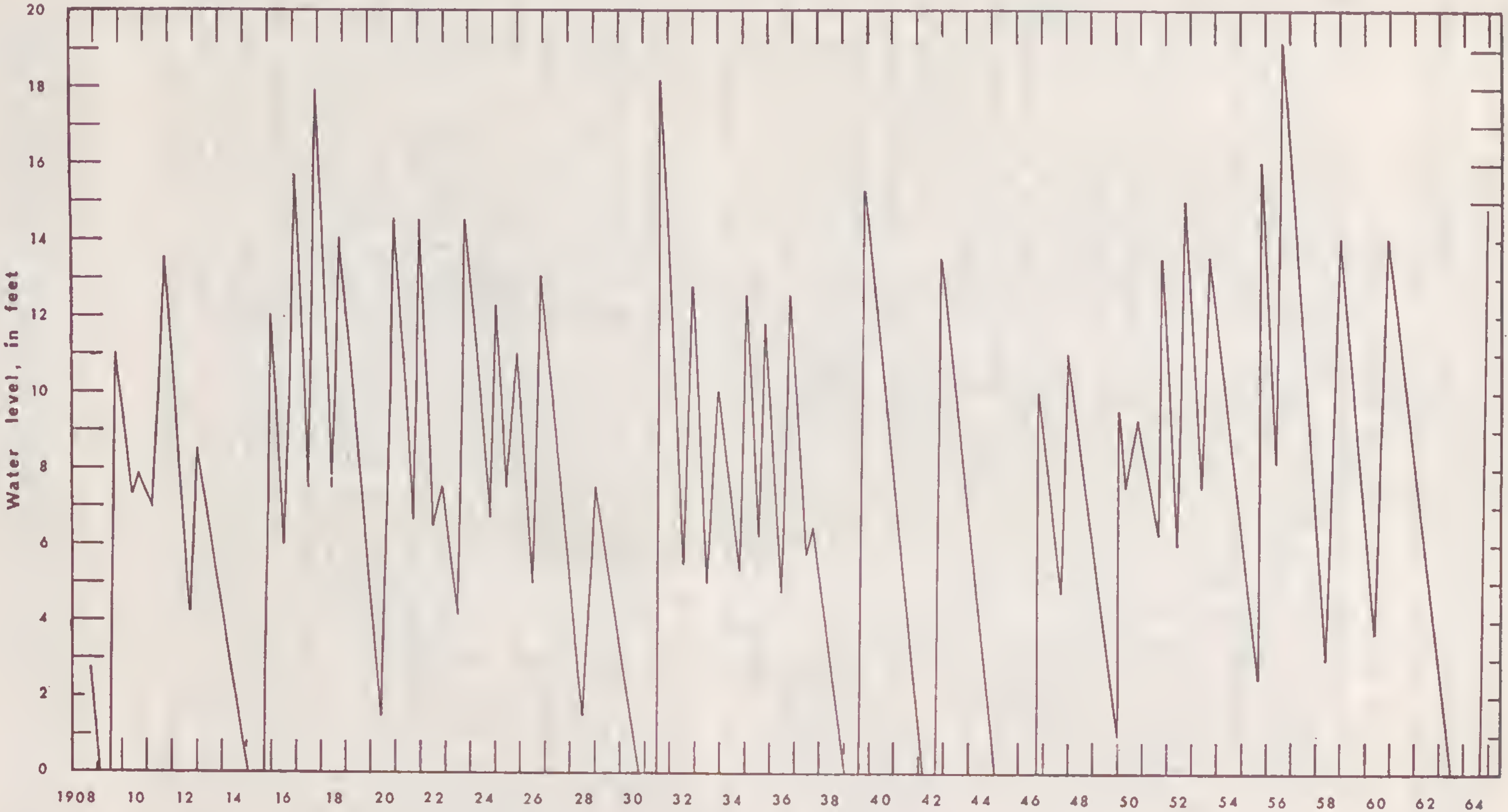

FIG. 2—L. Hattah Water Levels, 1908-1964. Only the highest and lowest levels reached during and after each flood have been plotted, the rises and falls being generalized by straight lines.

is probable that during the three decades after 1920 the sand dune area was flooded only 5 times. The situation is similar where the lakes overflow towards the east. In 1964, after about 83 days of rising water, the eastern lakes overflowed when Hattah reached a depth of 14′. Between 1923 and a series of high floods in the mid- and later-fifties, this depth was reached only in 1931, 1939, and 1952.

This admittedly is an inadequate picture of the sequence and frequency of flooding but it may be a useful basis for observations of future floods which, if there is already water in L. Hattah, may have different depths on the Hattah gauge associated with the various stages of the sequence of flooding.

As the penetration of the lake system by floodwater depends on the occurrence of high flows on the R. Murray, the records for the gauging station nearest upstream from the Chalka Ck inlet were examined in order to establish the relationships between the river flow and the regime of the lakes. From past observations (State Rivers and Water Supply Commission 1946) it has generally been accepted that for water to enter the flood system a corresponding flow of more than 16,000 cusecs must occur at Euston, and for 'flushing' of L. Hattah, so that water extends over a wider area than the confines of the lake depression and therefore joins the return flow to the R. Murray which follows the passage of the flood peak, a flow of more than 20,000 cusecs is required. When maximum flows at Euston, during floods which filled L. Hattah to more than its 8′ basin depth, are compared with the maximum depth of water recorded for each flood (Fig. 3), the high coefficient of 0·97 for linear correlation is obtained and, from regression analysis of the data, 19·7′ on the gauge at Euston, or a flow of more than 19,000 cusecs, will produce a level at the L. Hattah gauge of just over 8′. During the 1964 flood, water overflowed along Chalka Ck during September when the Euston gauge showed levels indicating flows of 18,000 to 20,000 cusecs. All available evidence then supports the use of 20,000 cusecs as the critical flow for flushing of the Hattah Lakes, a flow somewhat higher than a statistically determined 'bankfull discharge' (Robinson 1965). A multiple regression analysis between a number of variables was undertaken (Appendix A) to determine if other factors might have important effects on the depth of water recorded at L. Hattah as the result of a flood. The results of this analysis are expressed in the form:

$$Y = 0{\cdot}65X_1 - 0{\cdot}98X_2 - 4{\cdot}43$$

where Y is the rise of water level in L. Hattah, in feet,
X_1 is the maximum stage of flow at Euston, in feet,
X_2 is the level to which the lake had fallen prior to the flood, in feet.

Table 1 shows the predicted values of Y compared with the actual ones observed. The standard error of Y is 0·74, the greatest deviation of actual from predicted value is 1·5 in 1934 and 1942, the remainder have deviations of less than 1, and most are less than 0·5.

Conclusion

The establishment of the sequence and a comprehensive picture of the pattern of flooding of the Hattah Lakes flood system needs further careful observation during future floods. What have been tentatively derived are some depths of water in L. Hattah to be used as indicators of past flooding. More firmly established by regression analysis is that to predict the rise of L. Hattah to a high order of accuracy we need know only the peak flow of the flood at Euston and the level of water already in the lake. A further question to be asked is to what extent regulation of the R. Murray above Euston has changed the magnitude and frequency of peak

TABLE 1

Predicted compared with observed rises of Lake Hattah

Year	Observed	Predicted	Deviation
1934	7·17	8·70	— 1·53
1935	5·50	5·03	0·47
1936	7·75	8·59	— 0·84
1939	15·25	15·75	— 0·50
1942	13·50	12·01	1·49
1946	10·00	10·57	— 0·57
1947	6·25	5·98	0·27
1949-50	8·50	8·51	— 0·01
1950	1·00	0·99	0·01
1950	1·50	1·85	— 0·35
1951	7·25	7·74	— 0·49
1952	9·00	9·30	— 0·30
1953	5·50	4·62	0·88
1955	13·50	13·43	0·07
1956	11·00	10·18	0·82
1958	10·50	10·30	0·20
1960	10·33	10·07	0·26
1964	14·83	14·71	0·12

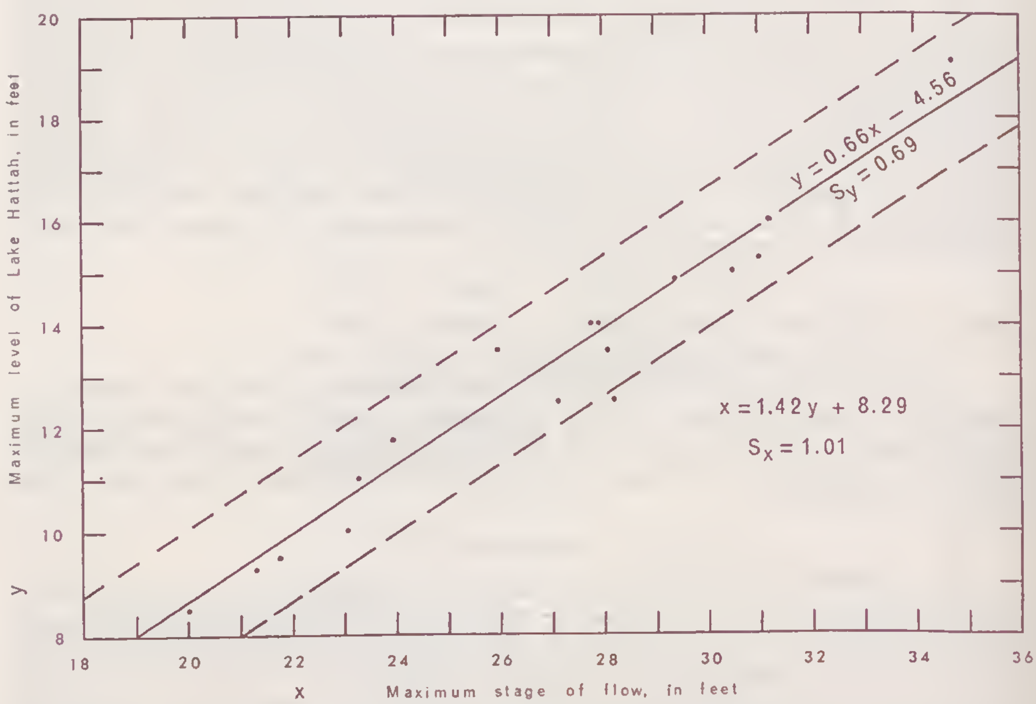

FIG. 3—Relationship of the maximum stage in a flood recorded at Euston and the highest water level reached in L. Hattah. The pecked lines are drawn at a distance . of 2 standard erors of Y from the regression line.

flows at Euston, and hence altered the scale and frequency of flooding of the Hattah Lakes? This will be dealt with elsewhere.

Acknowledgements

Assistanee from the University of Melbourne Researeh Fund is gratefully aeknowledged, as is the help given by a number of individuals and organizations. Mr E. M. Bibra of the State Rivers and Water Supply Commision supplied hydrographie data, and many other officers of that organization gave freely of their help and advice. The Victorian Railways Department supplied the records for L. Hattah. Mr K. J. Fairbairn eritically read earlier drafts of the manuscript.

Special thanks are given to Mr Eric McDonald, Warden of Hattah Lakes National Park. He made available his observations during the 1964 flood, and on many occasions gave freely of his local knowledge and hospitality. He is a never failing and enthusiastic source of encouragement for workers in the area.

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Explanation of Plate

PLATE 57

Fig. A—Rock bar across R. Murray at Chalka Ck Inlet.
Fig. B—Main inlet channel of Chalka Ck. This is immediately upstream of the bar in Fig. A.

Appendix A

MULTIPLE REGRESSION TO PREDICT THE RISE OF WATER IN LAKE HATTAH

Data considered relevant to determining a given rise in the water level of L. Hattah were punched on IBM cards for each flood occurring since gaugings began at Euston in 1930. The method of analysis of the data, using an IBM 7044 eomputer, was that deseribed by Efroymson (1960). The programme used to obtain the best fit of the set of observations of the independent and dependent variables is G2-001 in the University of Melbourne Computation Department Programme Library. With this programme, a stepwise multiple regression was earried out on 18 sets of data, each set containing values of 4 independent variables and one dependent variable, the rise of water level. In this method, one independent variable is added at a time, each addition being the one making the greatest improvement in goodness of fit, and a number of intermediate regression equations derived. A variable whieh is approximately a linear combination of other independent variables is not entered into the regression, and only statistieally signifieant variables are retained in the final regression.

The independent variables used in the regression were:

X_1. The maximum stage of flow at Euston in the flood. This is an indicator of the flood's ability to penetrate the anabranch system. From the nature of the build-up of flow and volume of water at a station well downstream in a large catchment area, it is expected that a flood with a given peak will be associated with the discharge of a predictable volume of water. A linear relationship exists between the peak flow and log-discharge of recorded floods at Euston, the Pearson product-moment correlation coefficient being 0·95. If both values were included in the data one would be rejected during regression analysis and the values that were actually observed, the maximum readings on the gauge at Euston, were the ones selected for inclusion.

X_2. The mimium level of the lake before the increment brought by the flood. Clearly, two similar floods may produce rises of different amounts because of differences in the size and shape of the basin which they are filling; the higher the initial water level, the wider the area over which a given volume of floodwater must spread and the smaller the rise in water level.

X_3. Time elapsed since the last inflow of water. Although it was thought that X_2 also represented this, and therefore the drought condition of the territory through which the floodwaters have to flow, there might be some extra weight given to a long drought when the lake level was at zero for several months.

X_4. Precipitation at Hattah over the rising water period. Some storms can produce more than a ½" of rain in a few hours and several inches of rain can fall while the water level of the lake is rising, the maximum being 927 points in 1956. Rain gaugings at Hattah are not complete for the whole period since 1930 and the figures included in the sets of data were derived from the gaugings at Ouyen, using a relationship obtained from the period of record when Ouyen and Hattah were both operational rain gauging stations.

TABLE 2

Correlation coefficients between pairs of variables in multiple regression

	X_1	X_2	X_3	X_4	Y
X_1	1	−0·06	0·10	0·59	0·67
X_2		1	−0·90	−0·08	−0·76
X_3			1	0·15	0·74
X_4				1	0·47
Y					1

Table 2 shows the linear correlation coefficients between the pairs of variables. X_3 was rejected from the analysis as it is inversely related linearly to X_2. X_4 was rejected as being not significant at the 5% level of F. X_1 and X_2 were highly significant at even the 0·1% level of F and were retained in the regression.


A


B

GEOCHEMICAL CONCENTRATION UNDER SALINE CONDITIONS

By R. J. W. McLaughlin

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Abstract

Chemical data are presented for the major and some of the minor elements in salt lakes in two areas of NW. Victoria—Linga and Tyrrell. Whereas evaporation of marine waters concentrates both sodium and magnesium, this latter is depleted in inland basins. This is due to incorporation of magnesium into clay mineral lattices. The mechanism of loss commences with biological reduction of gypsum to give calcium hydroxide. This precipitates magnesium hydroxide which absorbs silica to give poorly crystalline sepiolite. The oiigin of the high salt content of the lakes is oceanic, with a secondary concentration process by ion-filtration through clay membranes.

Introduction

In various part of the world, and especially in the interior of continents, there occur large bodies of water of a highly saline nature. These saline lakes are of much wider occurrence than is generally appreciated. In NW. Victoria, because of the low rainfall, flat topography, distance from the coast and ephemeral nature of the drainage pattern, conditions are propitious for large-scale development of saline basins. Two areas have been investigated, the L. Tyrrell system and the Linga lakes system—their localities are shown in Fig. 1. Samples were collected in early September 1963. In open lakes sampling was carried out about 100 ft from shore and at a depth of 1 ft below the surface.

Chemical determinations were carried out on the filtered solutions as soon as practicable. The methods used were as follows:

Sodium and potassium by flame photometry (Vogel 1961); calcium and magnesium by titrimetry w'.h E.D.T.A. (Welcher 1958); strontium by atomic absorption (David 1962, Willis 1963); chloride, bromide, carbonate, and boron by various titrimetric procedures (Wilson & Wilson 1962); sulphate by turbidimetry using $BaCl_2$ (Vogel 1961); silicon by colorimetry (Mullin & Riley 1955). Analyses were always at least duplicated.

Results

Chemical data given in Table 1 are expressed as parts per million. High concentrations are reduced by various powers of ten where indicated. In order that comparison may be made between samples, they have been reduced to a common basis by re-calculation of the three main cations, sodium, calcium, magnesium to proportions of 100%, and these have been plotted on a ternary diagram (Fig. 2). Various ratios between the chemical constituents have been calculated and they shed considerable light on the origin and evolutionary sequence of the waters. The cation and anion equivalents are in reasonable balance considering the high salinities.

Discussion

The proportions of sodium, calcium, and magnesium in the waters have been plotted in Fig. 2 and show that some samples are considerably enriched in sodium

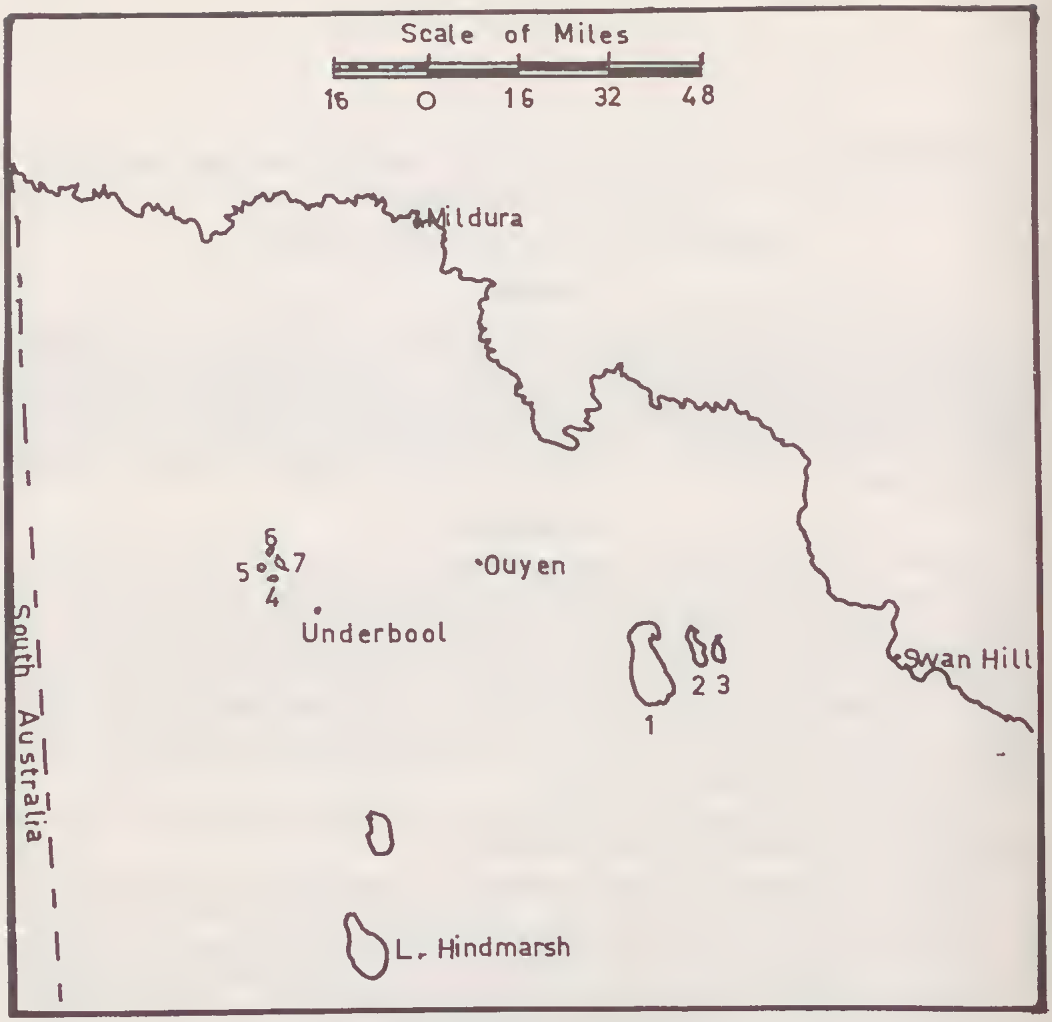

FIG. 1—Locality of samples.
Tyrrell group: 1, 2, 3—Lakes Tyrrell, Wahpool, Timboram.
Linga group: 4, 5, 6, 7—Lakes Nanya, Crosby, Sailor, Crescent.

relative to calcium and magnesium. It has not been possible to include total salinity on the diagram, but generally the higher the salinity, the closer the composition lies to the sodium end of the figure. This trend has been observed with other lake systems, but it has not been possible to plot all of the data because of the overlap on the diagram. Evaporation of oceanic waters has also been plotted on this diagram for three areas—Boccana de Virrila in Peru (Morris & Dickey 1957); Karaboghaz (Clarke 1916); Mediterranean bitterns (Stewart 1963). The concentration trend for these oceanic brines differs from that in a continental setting. Magnesium and sodium are both concentrated.

The loss of calcium relative to sodium and magnesium in inland basins is readily explained. Gypsum is actively being precipitated both as large twinned crystals,

TABLE 1

Analyses of saline waters of NW. Victoria

Element	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
$Na \cdot 10^{-2}$	348	312	940	700	1140	402	225	360	186	800	870	944	972	1020	1054	1070	105
$K \cdot 10^{-1}$	26	27	35	29	76	21	28	40	24	36	35	38	39	36	31	35	38
$Mg \cdot 10^{-1}$	344	297	304	243	731	261	228	424	169	163	208	225	291	295	169	169	135
Ca	786	694	1007	806	436	1100	1448	1350	1233	983	787	787	638	624	871	871	400
Sr	9·9	9·5	3·2	3·5	3·1	9·7	12·1	11·9	11·6	9·5	6·9	6·7	6·1	6·1	1·3	1·2	8
$Cl \cdot 10^{-2}$	595	532	1535	1125	1842	629	401	636	327	1274	1345	1469	1541	1586	1652	1703	190
Br	185	167	152	130	313	82	117	159	96	96	108	118	133	131	97	100	65
CO_3	22	11	36	26	71	92	48	121	88	62	55	61	85	74	48	35	145
$SO_4 \cdot 10^{-1}$	244	203	260	200	804	288	180	256	152	214	411	460	446	480	166	180	266
Si	7·8	3·7	0·5	0·8	0·4	1	0·8	5·5	1·1	5·6	0·5	0·6	1·3	0·9	0·2	0·2	3
B	8·3	5·1	0·9	0·5	2·4	2·9	5·7	0·9	6·6	3·5	1·2	0·5	3·5	3·0	1·4	1·9	4·6
pH	4·0	4·4	6·8	6·9	7·1	7·6	7·2	7·0	8·5	7·2	7·2	7·2	6·8	7·1	6·7	7·0	
Na/K	134	116	269	241	150	191	80	88	78	222	248	248	249	283	340	306	28
Ca/Sr	79	73	315	230	141	113	120	113	106	103	114	117	105	102	670	723	50
Cl/Na	1·7	1·7	1·6	1·6	1·6	1·6	1·8	1·8	1·8	1·6	1·5	1·6	1·6	1·6	1·6	1·6	1·8
Cl/SO_4	24	26	59	57	23	22	22	25	22	60	33	32	35	33	100	95	7·1
Cl/Br	322	319	1010	866	588	767	342	400	341	1328	1245	1245	1159	1210	1704	1703	292
$\frac{Na \cdot 10^2}{Na+Mg+Ca}$	89·2	89·5	95·9	95·6	93·6	91·5	85·8	86·3	86·4	96·8	96·8	96·9	96·5	96·6	97·6	97·6	85·7
$\frac{Mg \cdot 10^2}{Na+Mg+Ca}$	8·8	8·5	3·1	3·3	6·0	6·0	8·7	10·4	7·9	2·0	2·3	2·3	2·9	2·8	1·6	1·6	11·0
$\frac{Ca \cdot 10^2}{Na+Mg+Ca}$	2·0	2·0	1·0	1·1	0·4	2·5	5·5	3·3	5·7	1·2	0·9	0·8	0·6	0·6	0·8	0·8	3·3

The values in the table are all expressed as parts per million for the analytical data, and are reduced by various powers of ten where indicated. Localities are as follows: 1—Springs in the bed of Tyrrell Ck close to the Sea Lake—Chinkapook road. 2—Lagoon one mile N. of No. 1 and in the Tyrrell Ck deltaic area. 3—L. Tyrrell close to the salt works at the SW. end of L. Tyrrell. 4—Surface water in ponds on the flats adjacent to No. 3. 5—Extreme N. end of L. Tyrrell, water level circa one inch over extensive mud flats. 6—N. end of L. Wahpool. 7—S. end of L. Timboram. 8—N. end of L. Timboram. 9—Transient pool, dry in summer, near Tyrrell Downs. 10—L. Nanya, Linga Lakes, near Ouyen. 11—L. Crosby, S. end, Linga lakes. 12—L. Crosby, central region, Linga lakes. 13—L. Crescent, mid-point on S. side, Linga lakes. 14—L. Crescent, N. end, Linga lakes. 15—L. Sailor, Linga lakes (sampled in morning). 16—L. Sailor, as for 15 (afternoon sample). 17—Ocean—values taken from Goldberg (1963).

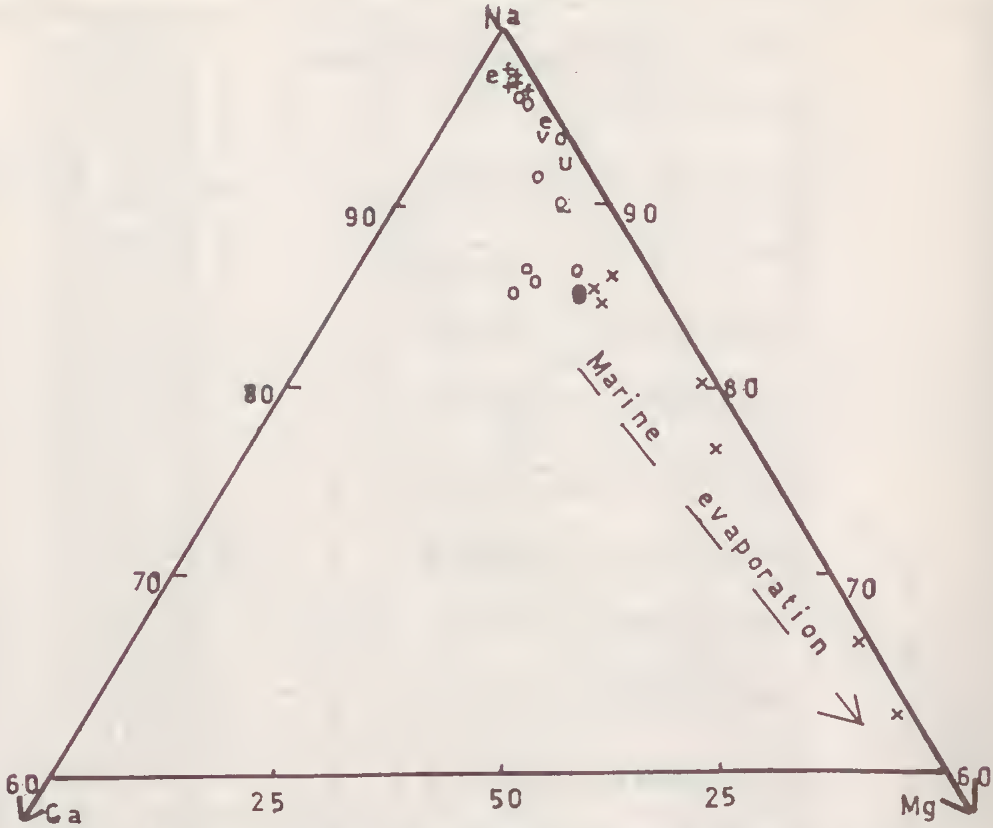

FIG. 2—Portion of the ternary diagram sodium, calcium, magnesium. Compositions of various waters have been plotted as described in the text. Overlap of various points has not been shown in full.

0—Lake Tyrrell group; + Linga lakes group; ●—ocean water; X—concentration of marine waters by evaporation (Boccana de Virilla, Karaboghaz, Mediterranean bitterns, Morris & Dickey (1957), Clarke (1916)); e—Lake Eyre (Bonython 1956); U—Lake Urmi, Persia; V—Lake near Shiraz, Persia (Clarke 1916).

(On evaporation under marine conditions compositions move to the lower right corner as shown. Under terrestrial conditions the compositional move is upwards.)

showing numerous solution and re-growth phenomena, and as fine-grained particles. The large crystals occur in bands and indicate previous strand lines which sometimes may be traced for long distances. They owe their development to variation in solubility, for the edge waters can reach high temperatures during sunny periods. Although, according to the literature, anhydrite should precipitate at high salinity (Posnjak 1940, Stewart 1963), no traces have been found. While this may be because of rapid conversion to gypsum as noted by Zen (1965), the explanation is probably much simpler. It is a common practice in the salt industry to reduce the solubility of gypsum by addition of a small amount (0·5%) of sodium sulphate (Madgin & Swales 1956). In all the uncontaminated waters examined there is excess of sulphate over calcium.

The depletion of magnesium is much more difficult to explain, for in the chemical system investigated magnesium salts are all very soluble. The simple explanation would be to assume concentration to the point where halite is precipitated, the magnesium-rich solutions lost by subterranean flow, then subsequent re-solution of halite. While this might be used to explain, at least partially, the Linga lakes, it may not be applied to the Tyrrell group. During crystallization of halite from water of oceanic composition, bromine is concentrated in the mother liquor. Subsequent solution of the halite gives a liquid of very high Cl/Br ratio (Stewart 1963). The Cl/Br ratios (Table 1) of the Tyrrell waters are too low to apply this explanation of loss by seepage. Numerous workers have explained the loss of magnesium (and perhaps calcium) in natural waters by ion-exchange processes (Hudson & Taliaferro 1925, De Sitter 1947, Degens 1965). This process is not applicable in the waters under discussion for the high sodium content should reverse the process, and any hydrogen exchange would cause low pH. Furthermore, recent work (Hanshaw 1964) indicates that compacted clays have preference for monovalent over divalent ions. A process which could explain the observed facts involves incorporation of magnesium into the lattice of clay minerals and would operate as follows. The presence and high activity of sulphate-reducing bacteria under anaerobic conditions is well known. Baas-Becking & Kaplan (1956) have given evidence of formation of sulphur from gypsum in L. Eyre, and Emery & Rittenberg (1952) have explained sulphate loss in recent sediments as arising from the same cause. All workers agree in classing the process as an important one, and that pH will rise due to $Ca(OH)_2$ formation (Degens 1965). While most authors then assume that the $Ca(OH)_2$ formed will precipitate almost immediately as $CaCO_3$ this is not necessarily true. A process of considerable technological importance to man is the extraction of magnesium from sea water by addition of $Ca(OH)_2$ to give the very insoluble $Mg(OH)_2$, the solubility of which is several orders of magnitude less than that of $CaCO_3$, especially in the presence of CO_2. This process must also operate in saline environments, but after precipitation of $Mg(OH)_2$ the $CaCO_3$ might then precipitate, although gypsum seems the more likely possibility. The process is one which would take place in the lacustrine muds. Harder (1965) has shown that freshly precipitated magnesium hydroxide is a very efficient scavenger of silica polymorphs. Quite apart from quartz derived from fluviatile and aeolian transport, silica will be added to the basins from other sources, e.g. opaline silica (Baker 1960). In reducing environments rich in organic matter silica becomes extremely soluble (Emery & Rittenberg 1952). The waters themselves would contain silica largely as the monomer because of pH and low concentration (Iler 1955). The precipitated magnesium hydroxide will scavenge any silica from solution to give an incipient clay mineral.

There are numerous pieces of evidence which substantiate the removal of magnesium by the method outlined. Silicon is comparatively high in the inflowing waters and pH is low (Table 1, No. 1); both alter rapidly. Other workers have recorded the occurrence of magnesium-rich clays from saline environments. Thus, Quaide (1958) recorded chlorite and suspected that it was the stable component; Boynthon (1956) recorded palygorskite at L. Eyre; the present writer has identified poorly crystalline sepiolite in the lacustrine muds of these basins. The type of clay identified and presumably formed by the process outlined above has strongly absorbent properties with respect to organic molecules. The organic products derived from planktonic organisms, e.g. carotenoids and the oily globules surrounding these pigments, would be absorbed (Hodge et al. 1956, Cane 1962). Later diagnetic changes, even pH variation, could release such organic material and under suitable conditions hydrocarbons might arise. Such thoughts are merely speculative, but certainly in accord with modern thought (Buneev 1944, Emery & Rittenberg 1952, Degens 1965). The point of importance in the present discussion is that the black evil-smelling muds of salt lakes are high in organic material, portion of which is of an oily nature. There seems no valid reason, therefore, why hydrocarbon deposits should not arise under highly saline conditions as well as in the usually accepted marine environment.

The geochemistry of the other elements follows normal courses. Potassium is lost relative to sodium as salinity increases due to absorption on clay particles. The Na/K ratios of Table 1 illustrate this point. Behaviour of strontium is complicated by gypsum precipitation. The Ca/Sr ratios rise when gypsum precipitation is active due to occlusion of strontium in the crystals. The rise in Cl/SO_4 ratio demonstrates concentration of chloride relative to sulphate.

The Cl/Br ratios are highly diagnostic in indicating the presence or absence of halite deposits in the underlying rocks through which water percolates into the lakes. The Tyrrell group ratios are too low to suggest such deposits, with the exception of No. 5 where halite had been precipitating prior to the time of sample collection. No. 3 & 4 are from an area close to the salt works and illustrate quite clearly by their high ratios, the re-solution of halite and its contaminating effect. The high value for No. 6 is puzzling; it may be due to back wash from soluble salts in the surrounding soils, but the real reason is not known. The Linga group (No. 10-16, Table 1) present a totally different picture. In every sample the high Cl/Br ratio indicates re-solution of salts; in some instances (No. 15 & 16) the lake beds themselves are halite. Despite this, the ratio Cl/Br is not sufficiently high to derive all of the bromide by re-solution of halite. Salts equivalent to the kieserite-carnallite zone would be required to give a Cl/Br ratio of circa 2000 (Kuhn 1955) and the cations of such salts are of insufficient concentration in the waters. Re-solution of halite would give values for Cl/Br which would be even higher. The Cl/Na ratios do not vary greatly, demonstrating that, while both are concentrated, neither undergoes any relative enrichment. They are fairly close to the ratio for oceanic water.

The behaviour of carbonate is a direct reflection of carbon dioxide content, and hence of biological, especially photosynthetic, activity. In Table 1, No. 15 & 16 were taken from the same position. The higher content of carbonate (No. 15) represents material sampled in the early morning; the lower content (No. 16) was sampled in the late afternoon.

The estimation of silicon was carried out by the molybdenum blue method (Mullin & Riley 1955). Because of the low content, all of the silicon estimated would have been present as silica monomer (Iler 1955). Silicon is lost as salinity rises. The Tyrrell group is instructive in showing the high content in the spring waters (Table 1, No. 1) and this rapidly drops as salinity increases. Boron behaves in a similar fashion and is presumably absorbed on to the clay lattice. It has been claimed (Keith & Degens 1959, Potter et al. 1963) that sediments in a marine environment have a higher boron content than terrestrial material. It should be noted that sediments developed under the saline basin conditions described, might also possibly be classed as marine if this method alone was used to characterize strata.

Origin

The source of the high salinities observed in these waters is probably eventually oceanic, because of various chemical similarities. Direct concentration of oceanic water, either surface or trapped pore water, resulting from the Tertiary marine transgression, does not seem possible because of the time lapse and the limited nature of the lakes. Deposition of salts blown from the arid interior is also rejected, not only because of internal evidence such as Cl/Br ratios, but also physical evidence of lack of aeolian transport in other localities, e.g. Fournier D'Albe (1955) in Baluchistan, and Bonython (1956) in L. Eyre.

Concentration from rain water, which normally contains small quantities of oceanic salts, is known as the 'cyclic salt hypothesis'. This has many adherents in Australia and elsewhere (Anderson 1941, 1945; Collins & Williams 1933; Hutton & Leslie 1958; Jack 1921; Jackson 1965; Loewengart 1962; Riffenberg 1926).

In rain, calcium increases relative to other cations with distance from the sea. This has been explained as resulting from small particles of calcium sulphate which are whirled aloft and not carried down by rain-out to such an extent as the more soluble constituents. These latter are deliquescent, form droplets, and so are lost closer to the coast (Ericksson 1952, 1959; Gorham 1958; Junge 1954; Squires 1956; Sugawara et al. 1949; Twomey 1955).

Woodcock et al. (1953) observed that bursting bubbles in the sea were very efficient removers of the surface oily layer resulting from planktonic organisms. This organic material should be highly concentrated in spray and because it possesses cation-exchange properties, it has been suggested as an explanation of differential sodium to chlorine enrichment in rain-water (Ericksson 1959). Since divalent ions absorb more strongly than monovalent, calcium should concentrate with the organic material. The present writer would suggest that such organo-calcic complexes should be hydrophobic, dry rapidly, and thus remain as aerosols. They would, in the interior of arid continents, be lost by fall-out as well as occasional rain-out. Much of the fine loess-like gypsum of the Australian interior (kopi) may have arisen by this mechanism and not by precipitation from a lucustrine or estuarine environment. The grain-size of the fine-grained kopi is not inconsistent with the type of material obtained technologically by spray-drying.

To explain the saline basins being discussed in this paper, as representing residual liquor due to evaporation of rain water 'in situ', does not seem to be satisfactory to the author. There are many areas in the region where the waters never beome more than slightly brackish, and these should also show high salinities, especially as they may often evaporate compltely. The problem is one which presents certain similarities to underground waters. With these latter it is current theory that salinity rise is due to differential ion filtration through negatively-charged clay membranes (Russell 1933, De Sitter 1947, Bredehoeft et al. 1963). In the geological section drawn by Johns & Lawrence (1964) a thick band of clay is shown as overlying sand, carbonaceous clay, and some lignite. This would be an ideal membrane under the above scheme of concentration. Fracturing of the membrane would give access to the saline waters concentrated beneath. In the Tyrrell region there is some evidence for buried ridges and valleys and saline springs are largely responsible for the lake waters (Hills 1939). Although the eventual source of the salts is oceanic, it is more than likely that differential dialysis is also an important process in the concentration process.

In conclusion, it is pertinent to note that different clays might well be expected to behave in varying fashions in their ion-membrane dialysis properties. Different rocks, or their weathered counterparts, might be expected, therefore, to concentrate salts in different fashions. The statement of Plinius thus takes on a new and more vivid meaning. 'Tales sunt aquae, qualis terra per quum fluunt' (Waters take their nature from the rocks through which they flow).

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36

VEGETATION STUDIES IN NORTH-WEST VICTORIA
I. THE BEULAH-HOPETOUN AREA

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Summary

The soil and vegetation interrelationships of an area of the Mallee Region of Victoria are discussed, and the original vegetation formations of the area reconstructed and mapped from remnants preserved along road reserves. Two distinct sub-formations are present: the *E. largiflorens* savannah woodland association which is restricted to the heavy clay soils of the flood plain of the Yarriambiac Ck, and a mixture of mallee scrub associations which dominate a complex of lighter soils of the rest of the area. The distribution of the various mallee eucalypts was analysed using positive interspecific correlation.

Introduction

The area studied comprises the parishes of Kallery, Carori, Goyura, and parts of the parishes of Gutchu, Byanga, and Galaquil. It covers approximately 200 square miles and is situated between the towns of Beulah and Hopetoun which lie on the Henty Highway approximately 250 miles NW. of Melbourne (Fig. 1).

Although the vegetation of the region is predominantly characterized by members of the multi-stemmed group of the genus *Eucalyptus* known as 'mallees', it is linked with grassland and savannah woodland communities to the south, by the species characteristic of the flood plain of the Yarriambiac Ck. The soils, too, show transitional properties, so that the area is appropriately referred to as 'Mallee Fringe' country. The boundary of the Murray Mallee Region passes through the area (Hills 1939).

There has been little previous work on soils and vegetation in the Victorian Mallee Region. Zimmer (1937) dealt only in very general terms with the country to the north. Newell (1961) described the soils of the Mallee Research Station, Walpeup, and included sparse notes on the vegetation. Rowan and Downes (1963) studied the whole of NW. Victoria; they used the land unit approach to describe the soils and their land use characteristics.

Physiography and Geology

NNW.-SSE. Ridges

The principal physiographic features are broadly undulating NNW.-SSE. ridges approximately 2 miles wide and spaced about the same distance apart. The most conspicuous of these are the two which govern the course of the Yarriambiac Ck, an effluent of the Wimmera R., through the area studied. These two ridges arise at Jung, 60 miles to the south, and continue N. to Hopetoun. Other less conspicuous ridges can also be located, although in the country farther north they are obscured by the E.-W. dune component.

Hills (1939) considered these ridges to represent faulting and warping in the buried bedrock upon which the Cainozoic rocks of the Mallee Region rest. This view has not been supported by later workers; Blackburn (1962) believed them to represent stranded coastal dunes of the receding Miocene Murray Gulf. In the

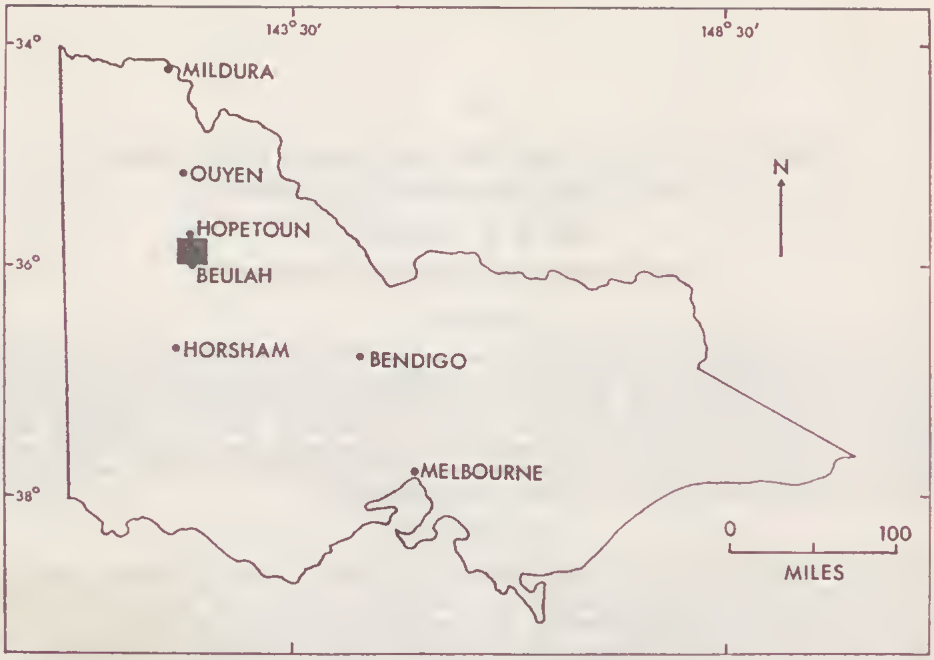

Fig. 1—Location of the area.

Beulah Area much of these NNW. ridges has been overlain by Recent sands of an E.-W. dune system. Wherever the E.-W. dune system is absent from the ridge surface, ironstone gravel can be found exposed, indicating perhaps a fossil soil formation and certainly an older land surface. At present, we can only speculate on the age of these structures; as a buried topography they could be of Pliocene age (cf. Northcote (1951) at Coomealla, New South Wales); as stranded dunes they might be Pleistocene. Sprigg (1952) suggested that the beginning of the Pleistocene corresponded with the eastern series of inland stranded coastal dunes which are associated with the Kanawinka fault running through Naracoorte, South Australia. However, no reliable dating is available and the Plio-Pleistocene boundary remains indefinite (E. D. Gill pers. comm.).

Inter-Ridge Valleys

The valleys between the NNW.-SSE. ridges are based upon estuarine and fluviatile silts and clays deposited by the drainage system of the newly elevated Pliocene Murray Gulf. These deposits are covered to varying extents, or have their surface layers contaminated with accessions of sandy material from the NNW.-SSE. ridges, E.-W. dunes (see below), and by regional dust (parna) carried in by the prevailing winds. Although this must have been the condition 80 years ago before settlement, it is difficult to tell how much of the intermingling of ridges and valleys, so noticeable at the present time, has resulted directly from the large scale clearing that commenced around 1880.

Yarriambiac Creek

The Yarriambiac Ck and its floodplain have characteristic soils and vegetation and, together, are appropriately considered as a distinct physiographic unit.

E.-W. Dunes

Recent sands have encroached westwards on to the area from stranded coastal dunes (Crocker 1946) and from previous courses of the R. Murray (Sprigg 1959). These have been shaped under the influence of the prevailing winds, by a combination of wind channelling and sand shepherding, to form parallel dunes. The dominant winds in the Victorian Mallee Region are westerlies so the resultant dunes trend E.-W. On the broader, Australia-wide scale, these dunes fit into the anticyclonic pattern suggested by King (1960).

In the very recent past, calcareous loess has been deposited over the whole area by wind winnowing and sifting of calcareous coastal dunes in South Australia (Crocker 1946). This has led to limestone horizons either as hard bands or soft or hard rubble in many soil profiles. That soil formation has been intermittent can be seen in the series of limestone bands in some profiles (Hills 1939). Drifting non-calcareous sand hills in virgin scrub show that soil formation is only poorly developed in adjacent areas. It is likely (Crocker 1946) that primary colonization of these aeolian materials began as recently as 4,000 years ago.

Lunettes

Attention was first drawn to these special landforms in the Echuca district and in the parish of Benjeroop, Victoria, by Harris (1939). Hills (1940) proposed a theory for their genesis and named them lunettes. Stephens & Crocker (1946) showed later that the theory of loessial accession suggested by Hills is not generally applicable. The lunettes are formed, as Harris originally pointed out, from material derived from the floors of the adjacent, associated depressions during periods in which they are dry. The loessial contributions suggested by Hills are intermittent and of only minor importance.

Two large lunettes are found in the area and their outlines are shown on the map (Fig. 4) adjacent to the E. margin of the creek flood plain. In addition, a number of smaller, less obvious but similar structures are found throughout the area. Because of the greater influence of sand drift in the Mallee Region, there is an appreciable percentage of saltation material in the lunettes in contrast to the more clayey formations of the Wimmera Region.

The water surfaces once associated with these lunettes have now subsided. They were previously linked with the now dwindling floodplain of the Yarriambiac Ck.

Climate

Meteorological data for the region are scarce, although a good synopsis of available information has been prepared by the Commonwealth Meteorological Bureau and published in Resources Survey—Mallee Region (Anon. 1952). A summary of the data for Beulah is made in Fig. 2. Rainfall varies from 14·3" per annum in the south to 13·2" per annum 20 miles to the north. Rosebery, with an annual rainfall of only 12·4", is anomalous, for it lies S. of Hopetoun and presumably nearer the 14" annual isohyet. Although rainfall is certainly of high winter-spring incidence, 40% of the rainfall falls in the summer and autumn months outside the growing season of cereal crops.

The average frost-free period (36°F +) is 232 days.

Drainage

No streams arise in the area but the Yarriambiac Ck, an effluent of the Wimmera R. at Longeronong, has its northward course through the study area.

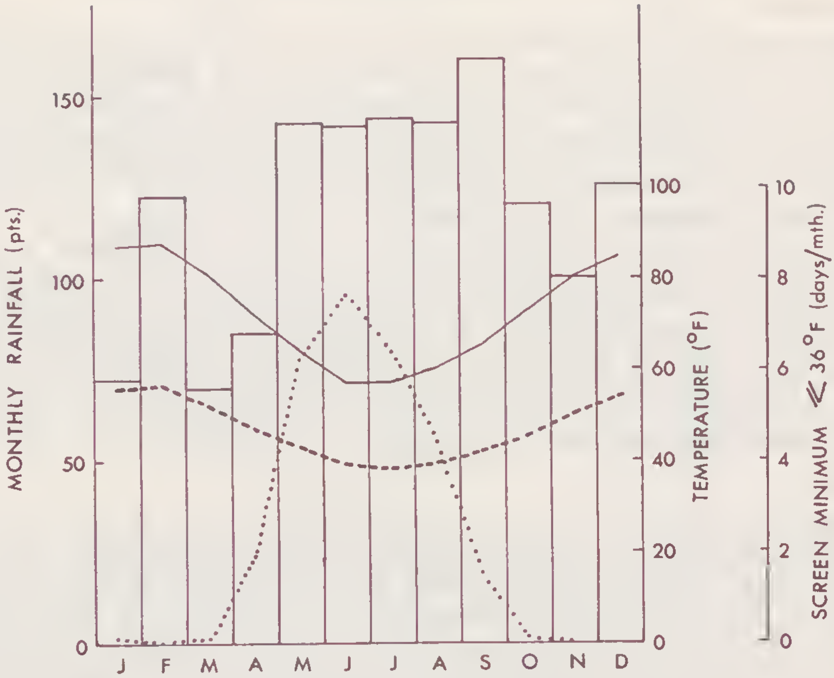

FIG. 2—A summary of climatic data for Beulah. Histogram of monthly rainfall. Mean monthly maximum (——) and mean monthly minimum (-----) temperatures, and the monthly frequency of screen temperatures equal to or less than 36°F (···).

Water rarely reaches beyond Warracknabeal (22 miles S. of Beulah), although in 1956, which was an exceptionally wet year throughout the State, water reached as far north as L. Coorong where it flooded cereal crops sown on the dried-out lake bed. L. Coorong is situated ½ mile SE. of Hopetoun and is the depression in which the Yarriambiac Ck terminates.

Soils

A consideration of geological history and physiographic development suggests a pedogenic pattern as shown by Fig. 3. This pattern is borne out by field observation within the area. The three types of parent material, indicated in the centre of the diagrammatic representation, have varied with time depending upon a great number of factors, many of which were operative in neighbouring physiographic zones. Groups B, D, and F cover a whole range of soil types in which the contribution of each parent material varies widely. An important consideration is that, since alluvial material predates saltation material and parna, the soils in Group F can show the morphological feature of a sudden transition to a clay subsoil. The surface layers represent later accumulations of lighter wind-borne material. The transition is not a result of pedogenic processes acting on a given parent material, as for example, in the formation of a red-brown earth.

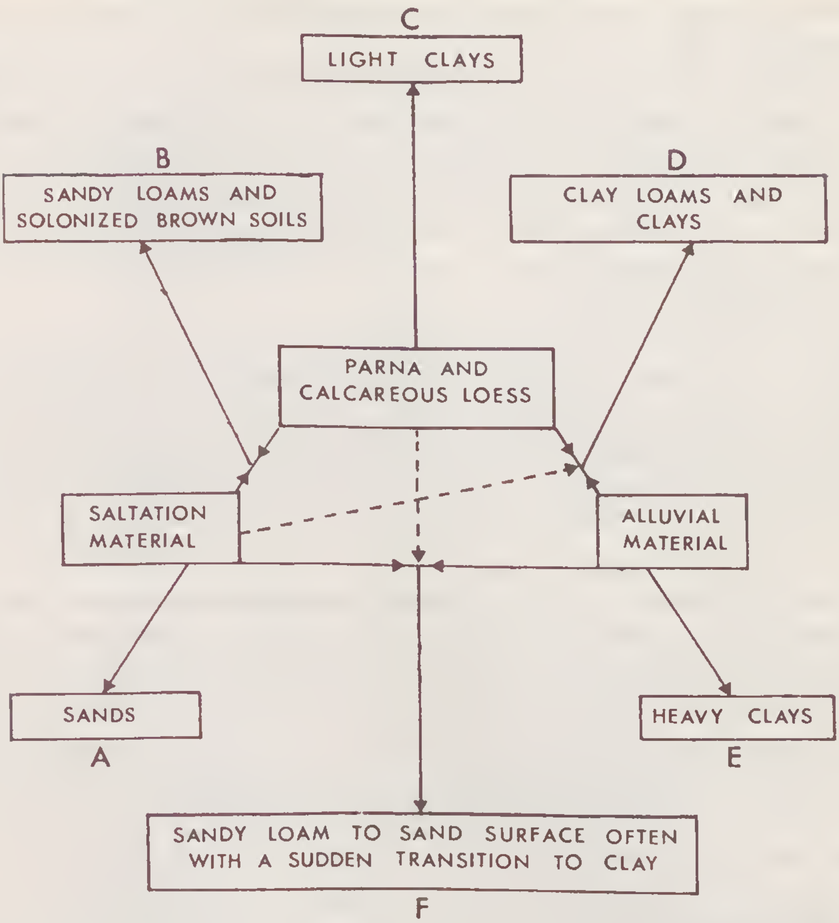

FIG. 3—Relationship between Parent Materials and Soils in the Beulah-Hopetoun area.

Despite the variability and intergradation of soil types, it is convenient to deal with the soils of the area in three broad groups related to the physiographic divisions of ridge and dune, valley, and creek flood-plain.

Representative profiles are described in Appendix 1, although with such a wide variation in soil characteristics they do not go very far in defining the soil system of the area. Much additional information on the soils can be obtained from Newell (1961), who has described similar soils in detail and indicated their variations for the Mallee Research Station, Walpeup, some 70 miles N. of the study area.

Sandy Soils of Ridges and Dunes: Groups A, B

The older sands of the NNW.-SSE. ridges are deep coloured, mostly in tones of red, whereas the later additions which form the E.-W. dunes are lighter and more yellow in colour. King (1960) speaks of 'white sands' as opposed to 'red sands'. At the present time the depth of loose sand is variable, but in general terms depth is greater on the dunes than on the ridges. This is not, however, invariably the case. Once again it is difficult to estimate the effects of the accelerated erosion of the past 80 years.

A limestone layer, which is an important feature of most soils in this grouping, is very variable both in type and in position. Not all soils have massive limestone in the profile, but most are highly calcareous. In some instances, erosion has exposed limestone rubble on the surface and upon this a further profile is developing.

No fertility differences are noticeable in the sandy soils. Crop growth is so dependent upon the moisture regime that major variations in yield can easily be attributed to either seasonal rainfall, pre-cropping treatment or both. Under the prevailing rainfall the water relations in these sandy soils are fair for cereals and good for deep rooted species.

Loams and Light Clays of the Inter-Ridge Valleys: Groups C, D

Surface texture and depth to subsoil vary considerably in these soils but can usually be related to the proximity of a sand source. Once again, the precaution is added that it is difficult to estimate the changes in the nature of the surface soil in the years following clearing. For the major part these soils have less than 6 in. of light material overlying the clay subsoil, although on roadsides it is possible to see up to 2 ft or even more of sandy accession collected against fences. Many fences in the area are lifted every few years; in other cases completely new fences have been erected over existing ones.

In the uncultivated state these soils show the gilgai micro-structure so common in the heavy soils of regions of sparse rainfall. In summer, when these soils dry out, they crack deeply and particles of the surface soil fall down the cracks adding to the bulk of the soil below. On rewetting, the clay minerals of the subsoil, when of the type that swell greatly, exert increased pressure which is relieved along lines of weakness to form the characteristic mounds on the surface. Since the alternative name 'crabhole' infers depression formation, the aboriginal name gilgai is preferred (Leeper 1957). Under repeated cultivation these minor surface fluctuations tend to be ironed out. In paddocks in which no gilgai formations are prominent it is possible to pick up their existence on 20-chains per inch aerial photomaps.

The clay soils have poor moisture relationships and consequently their usefulness for agriculture, even with the fallow technique, is largely governed by rain falling in the growing season.

Soils of the Creek Flood Plain: Group E

In some cases these soils correspond closely with those of the previous group, but in more typical locations they are equivalent to the grey and brown self-mulching, gilgai soils of the Wimmera plains such as have been described by Skene (1954, 1959), and in equivalent locations by Zimmer (1937), Beadle (1948), and Specht (1951).

In some places, which from aerial photography appear to be related to old courses of the Yarriambiac Ck, a soil with a red clay surface is found. Two profiles taken 20 yds apart on the same ground level describe the two contrasting soil types (Appendix 1, profiles 1a, 1b). It seems probable that these soils have formed on different parent materials and perhaps under different drainage conditions related in some way to previous courses of the Yarriambiac Ck.

Vegetation

The classification of the vegetation formations and the structural formulae applied to them follow Wood & Williams (1960). One alteration in their nomenclature, however, is considered necessary. This is to re-name their formation sclerophyll-shrub-woodland (T/S_1S_2(d)) as sclerophyll-scrub. The word woodland has been misused in this structural series, in which the spacing of the tallest stratum is dense (d). If this alteration is made, the Mallee, a multi-stemmed sub-form of the sclerophyll-scrub formation, is terminologically as well as structurally distinct from the woodland formation and, in particular, the sub-form savannah-woodland.

In the Beulah-Hopetoun area, only these two sub-forms, mallee and savannah-woodland, are present.

Savannah Woodland TG(m.d.)

The *Eucalyptus largiflorens** association is confined to the heavy textured, alkaline, gilgai soils (Group E) of the flood plain of the Yarriambiac Ck and to a few isolated patches of internal drainage among the mallee sub-formation in the inter-ridge valleys. The association has been described for equivalent habitats in New South Wales (Beadle 1948), South Australia (Specht 1951), and also in Victoria (Zimmer 1937). An occasional tree of *Casuarina leuhmannii* or *Myoporum platycarpum* is found with *E. largiflorens. Casuarina* forms extensive stands in the Wimmera but in this area it is restricted to the *E. largiflorens* association. *Myoporum*, a species common in more arid environments, occurs scattered throughout the area.

* The authorities for species names are contained in Appendix 2—Species Lists.

Mature trees of *E. largiflorens*, which may be up to 60 ft high, have a characteristic rounded crown with lower branches often drooping to the ground. It is difficult to be sure of the spacing of the trees in the natural condition except to say that they fit into the mid-dense (m.d.) classification of Wood & Williams (1960), i.e. spacing greater than twice the crown diameter.

The ground cover was probably originally dominated by the genera *Danthonia* and *Stipa* but is now largely replaced by a weed flora. Only occasional shrubs such as *Acacia oswaldii* and *Eremophila longifolia* are present. A list of species collected in this association is provided in Appendix 2.

Mallee T/S_1S_2(d.)

Members of this multi-stemmed group of the genus *Eucalyptus* comprise the dominant species of the most widespread vegetation sub-formation of the area. Height of the mallees varies from as low as 10 ft to as high as 40 ft in some cases. The tallest specimens are *E. behriana* growing in the wetter sites within its distribution. These specimens which are included in the structural formulae as T/S_1, are often single stemmed but present a gradation from this form to the mallee habit. Spacing of the eucalypts is dense, in many cases with touching canopies. Low shrubs (S_2), especially of the genus *Acacia*, are common. In the ground layer there is a noticeable contribution by the semi-succulent members of the family Chenopodiaceae which link the vegetation of this region with the more arid vegetation to the north. It is because of the presence of these plants that the term 'semi-arid mallee' has been applied to the drier end of the mallee sub-formation (Wood & Williams 1960).

A major part of the study of this area was concerned with analysing the distribution of the various mallee species. Traverses were made along all passable roads in the area, and at 0·3 mile intervals the dominant species and surface soil characteristics were recorded. Additional recordings were made at any opportunity. Since most of the area is cleared and under cultivation the only vegetation remaining is found along the roads. In most cases this is regrowth following 'rolling' or burning in the past. As the lignotuber present in mallee eucalypts enables the species to survive either of these methods of destruction, it is assumed that the natural distribution of these species has not been upset by the intervention of man. The texture of the surface soil at each site was noted at a suitable distance inside adjacent paddocks. This position was selected because the roadside vegetation and fences, which frequently show accumulations of wind-borne material from the adjacent farmlands, are much lighter in surface texture than they were under natural conditions. Within limits, surface soil texture indicates the position of any site in respect to ridge, dune or inter-ridge valley.

The most common mallee eucalypts in the area are: *E. oleosa, E. dumosa, E. calycogona, E. behriana.* Others present are *E. gracilis, E. viridis, E. incrassata* var. *costata*, and *E. foecunda.* From each of 503 sites which fell within the mallee sub-formation, the percentage of sites of each surface texture carrying each of these species was calculated. These data are presentd in Table 1.

Table 1

Distribution of the Major Mallee Eucalypts with Respect to Surface Soil Texture

(% of sites of a given textural class which contain each species)

Species	Surface Soil Texture					
	Loamy sand ls	Sandy loam sl	Sandy clay loam scl	Clay loam cl	Sandy clay sc	Clay c
E. behriana	4	33	50	76	98	100
E. dumosa	95	100	90	89	79	44
E. calycogona	41	61	57	54	17	0
E. oleosa	94	85	53	27	6	0
No. of sites in each textural group	155	100	90	96	53	9

The pattern which shows up so well in these data is not always obvious in the field; however, the large number of sites studied has enabled distribution to be analysed with confidence. *E. oleosa* shows a strong preference for the soils of the lightest surface soil texture class. The occurrence of this species quickly drops on soils with increasingly heavier surface soil texture. *E. behriana* on the other hand is found more frequently on the heavier surface soil texture types, but a noticeable feature is that it is more tolerant of lighter surface textures than is *E. oleosa* of the heavier surface textures.

The explanation of this lies in the surface soil texture distribution in the area. What is being shown is that *E. behriana* is limited almost entirely to soils of the valleys. Such soils have a range of surface soil textures from sandy loam to clay with an increasing incidence in the latter two classes. This is a result of erosive processes which have been stressed previously. On the other hand, *E. oleosa* is restricted to the soils of the ridges and dunes, which do not have a wide surface soil texture distribution, but which are largely of the two lightest classes. The spread of each species towards the other end of the surface texture scale is a measure of the mixing of the two species at the ecotonal boundaries.

The distribution of *E. calycogona* and *E. dumosa* show no striking relationship but appear to extend over the whole range of surface soil texture classes. The noticeable drop in the distribution of *E. dumosa* on the clay surface soil texture class shows up in x^2 tests in Table 2. *E. behriana* which is prominent on these soils is non-randomly distributed with *E. dumosa*. It is considered that this non-randomness is built up on these soils of heavy surface texture, and that *E. dumosa* does, as Table 1 illustrates, give way on these heavy surface soil types to *E. behriana* which then exists as a pure stand. The wide ecological range of *E. dumosa* can be partly answered by indicating that it really consists of a species complex. Although such a statement may be true of many species one would care to study, it is significant that a portion of the material included under the

TABLE 2

Association of dominant Mallee species

o *E. oleosa* c *E. calycogona*
b *E. behriana* d *E. dumosa*

i

c \ o	+	−
+	157	74
−	142	130

χ^2 12.9

ii

d \ o	+	−
+	283	174
−	16	30

χ^2 12.8

iii

b \ o	+	−
+	49	143
−	250	61

χ^2 148.2

iv

d \ c	+	−
+	216	241
−	16	30

χ^2 2.62

v

b \ c	+	−
+	89	129
−	143	142

χ^2 4.34

vi

b \ d	+	−
+	186	32
−	271	14

χ^2 14.18

Test		χ^2	Distribution	Probability
i	o x c	12.9	non random	< 0.01
ii	o x d	12.8	"	< 0.01
iii	o x b	148.2	"	<< 0.001
iv	c x d	2.62	random	> 0.05
v	c x b	4.34	"	> 0.05
vi	d x b	14.18	non random	< 0.01

name *E. dumosa* does in fact bear strong resemblance to the type specimen of *E. pileata* Blakely. Other material shows intermediary characters. A similar situation has recently been shown to exist on Eyre Peninsula, South Australia (Smith 1963).

Another way of expressing the distribution of the mallee eucalypts, which is independent of soil characteristics, involves the use of contingency tables (Goodall 1953). With the large number of sites available, it is possible to place a good deal of reliance on the outcome of these tests. Straightforward 2 × 2 presence and absence tables for pairs of species are the most useful, since higher order tables are generally difficult to interpret.

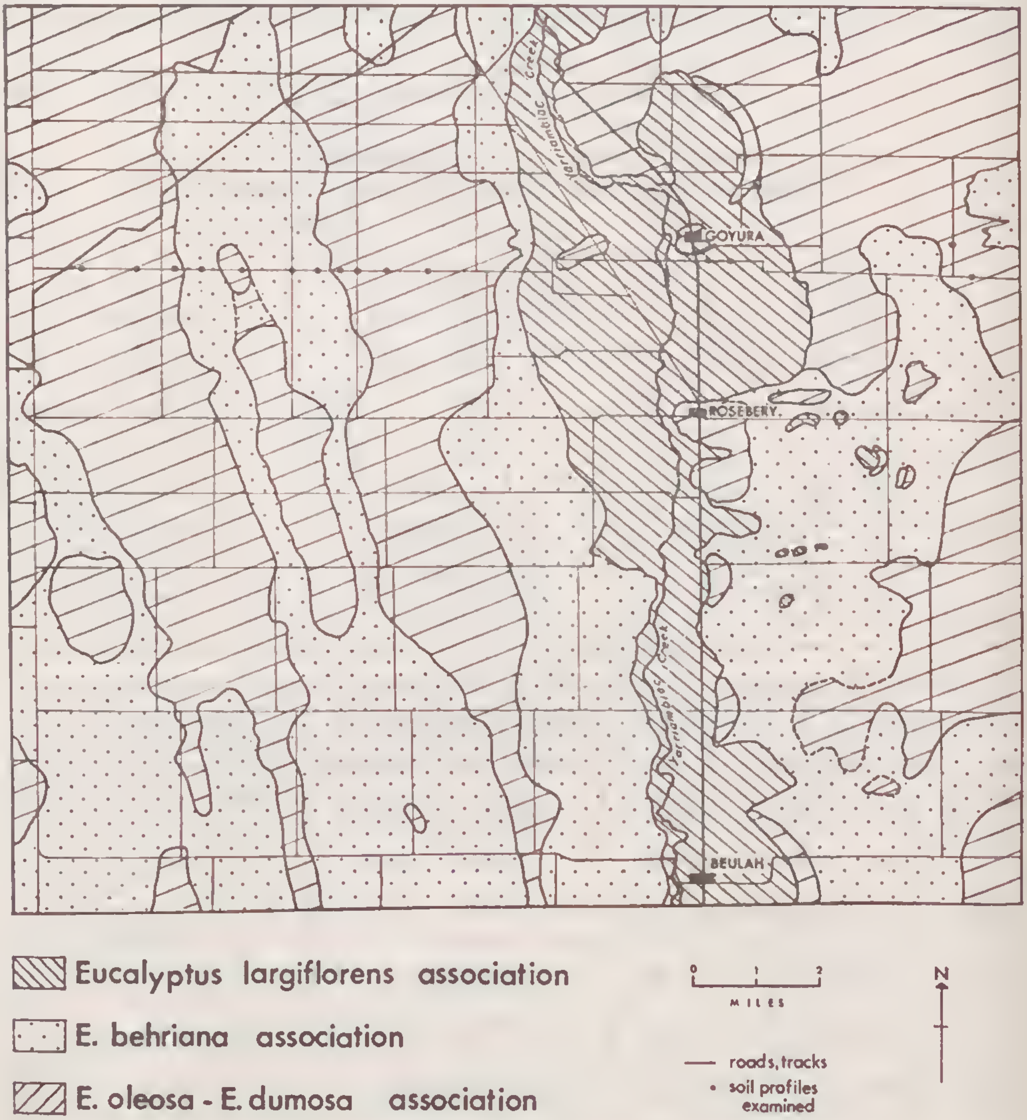

FIG. 4—Vegetation map for the Beulah-Hopetoun area.

Table 2 summarizes the results of x^2 tests carried out on the four major eucalypts. The most noticeable feature is the wide separation of *E. oleosa* (o) and *E. behriana* (b) which, using surface soil texture characteristics, occupy contrasting physiographic positions.

The distribution of *E. dumosa* follows that of *E. oleosa* but it is largely segregated from *E. behriana*. *E. calycogona* appears to occupy an intermediary position linking *E. oleosa* and *E. behriana*, which occupy the extreme physiographical and pedological positions in the area.

From the above observations the mallee sub-formation of this area has been divided into two parts, viz. the *E. behriana* association and the *E. oleosa-E. dumosa* association (Fig. 4). These correspond to valley and dune areas respectively.

Observations on the less common mallee species do not lend themselves to any statistical analysis. *E. incrassata* was found on six sites which were in the loamy sand surface texture class, and for three of these sites, at which soil cores were taken, the depth of sand exceeded the 54-in. range of the soil sampling tube. It would appear that *E. incrassata* is limited to those situations with the deepest surface sand layers—sites which are usually associated with the E.-W. dune component.

A species list for the component associations is presented in Appendix 2.

TABLE 3

Plant Associations of the Beulah–Hopetoun Area

Sub-Formation	Structural Formula	Community	Rainfall (in. per annum)	Soils
Savannah Woodland	TG (m.d.)	1. *E. largiflorens* association	14·3–12·4	Grey, brown soils of heavy texture associated with the flood plain of the Yarriambiac Ck
Mallee	T/S_1S_2 (d)	2. *E. behriana* association	14·3–12·4	Light clays of the inter-ridge valleys
	S_1S_2 (d)	3. *E. oleosa–E. dumosa* association	14·3–12·4	Solonized brown soils with sand up to 3 ft deep
	S_1S_2 (d)	4. *E. incrassata** association	13·2–12·4	Sandy soils with depth of sand > 4 ft, associated with the younger E.–W. dune system

* Rare in this area.

Discussion

In Table 3 the relationships between the structure and distribution of the vegetation associations present in the area are summarized. The distribution of these associations is recorded on a map of the area (Fig. 4).

Acknowledgements

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Mr J. H. Willis of the National Herbarium checked the identifications of the plant collection used in assembling Appendix 2. Miss J. Wood did the hand lettering on Fig. 4.

I would like to thank Dr R. L. Specht for his encouragement throughout the project and for his help in the preparation of this paper.

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Explanation of Plate

PLATE 58

Fig. a—*E. largiflorens* association, in this case with *Muehlenbeckia cunninghamii*.
Fig. b—*E. oleosa-E. dumosa* association.

Appendix 1

REPRESENTATIVE SOIL PROFILES FROM THE BEULAH-HOPETOUN AREA

1. *Eucalyptus largiflorens* association (Savannah Woodland Sub-formation)
   (1 mile S. of Goyura)
   - (a) 0-6″ grey (10YR5/1) (Munsell 1948) light clay breaking down to fine granular aggregates when dry. Fine calcium carbonate concretions.
     - 6-12″ dark grey (10YR4/1) medium clay of blocky structure. Friable with slight soft calcium carbonate concretions.
     - 12-48″ gradual transition to greyish brown (2·5Y5/2) medium clay high in calcium carbonate.
     - 48″ continuing.
   - (b) 20 yds from (a)
     - 0-6″ dark reddish brown (5YR3/4) medium clay forming a surface seal after rain.
     - 6-12″ dark red (5YR3/6) medium clay with blocky structure.
     - 12-48″ gradual transition to yellowish red (5YR4/6) medium clay high in calcium carbonate.
     - 48″ continuing.
2. *Eucalytus behriana* association (Mallee Sub-formation)
   (5 miles W. of Goyura)
   - 0-3″ dull reddish brown (5YR4/4) sandy loam showing stratification, and having a clear boundary with
   - 3-10″ dark reddish brown (5YR3/4) sandy clay loam increasing gradually in texture to
   - 10-24″ reddish brown (5YR4/4) light clay with slight lime passing to
   - 24-42″ yellowish-red (5YR4/6) medium clay with pale-brown mottling and moderate lime
   - 42″ continuing.
3. *Eucalyptus oleosa-E. dumosa* association (Mallee Sub-formation)
   (4 miles W. of Goyura)
   - 0-5″ reddish brown (5YR4/4) sandy loam with slight fine soft lime.
   - 5-20″ soft lime increasing with depth.
   - 20-30″ dull reddish brown (5YR4/4) sandy loam with massive travertine layer.
   - 30-39″ yellowish-red (5YR4/6) light sandy clay with medium lime and rubble.
4. *Eucalyptus oleosa-E. dumosa* association (Mallee Sub-formation)
   (7 miles W. of Goyura)
   - 0-3″ dull reddish brown (5YR4/4) sandy loam with organic matter
   - 3-27″ dull reddish brown (5YR4/4) sandy loam sharp boundary with
   - 27-33″ red sand (2·5YR4/6) grading into
   - 33-39″ red sand (2·5YR4/6) with soft limestone rubble
   - 39″ + heavy limestone rubble.

APPENDIX 2

A List of Plants Recorded Growing in the Component Associations

1. *Eucalyptus largiflorens* association
2. *E. oleosa–E. dumosa* association
3. *E. behriana* association

An asterisk before a species name indicates that the species is introduced.

	1	2	3
CUPRESSACEAE			
Callitris preissii Miq.	–	+	–
GRAMINEAE			
* *Ehrharta calycina* Sm.	–	+	–
Distichlis distichophylla (Labill.) Fasset	+	–	–
* *Lolium perenne* L.	+	–	+
* *L. rigidum* Gaudin	+	+	+
* *Bromis mollis* L.	+	–	+
* *B. diandrus* Roth	–	+	+
* *B. rubens* L.	+	+	+
* *Hordeum leporinum* Link	+	+	+
* *H. hystrix* Roth	+	+	+
* *Avena fatua* L.	+	+	+
* *Aira caryophyllea* L.	+	+	+
* *Phalaris minor* Retz.	+	–	–
Agrostis avenacea J. F. Gmel.	+	–	–
Chloris truncata R.Br.	+	–	–
Cynodon dactylon (L.) Pers.	+	–	–
* *Schismus barbatus* (L.) Thell.	–	+	–
Danthonia setacea R.Br.	+	+	–
D. caespitosa Gaudich.	+	–	+
Stipa platychaeta D. K. Hughes	–	+	+
S. aristiglumis F. Muell.	+	+	–
S. variabilis D. K. Hughes	+	+	+
S. nitida V. S. Summerhayes and C. E. Hubbard	–	+	–
S. drummondii Steud.	–	+	–
S. eremophila F. M. Reader	–	+	+
Panicum prolutum F. Muell.	–	–	+
* *P. milaceum* L.	–	+	–
CYPERACEAE			
* *Cyperus eragrostis* Lam.	+	–	–
Eleocharis acuta R.Br.	+	–	–
Carex inversa R.Br	+	–	–
JUNCACEAE			
Juncus pallidus R.Br.	+	–	–
J. filicaulis Buch.	+	–	–
LILIACEAE			
* *Asphodelus fistulosus* L.	–	+	–
Bulbine bulbosa (R.Br) Haw.	+	–	–
Dianella revoluta R.Br.	–	+	+
CASUARINACEAE			
Casuarina luehmannii R. T. Baker	+	–	–
PROTEACEAE			
Hakea vittata R.Br.	–	+	–
LORANTHACEAE			
Amyema miquelii (Lehm.) Van Tiegh.	–	–	+
SANTALACEAE			
Santalum acuminatum (R.Br.) A.DC.	–	+	+

APPENDIX 2—*continued*

	1	2	3
POLYGONACEAE			
* *Polygonum aviculare* L.	+	+	—
* *P. bellardii* All.	—	+	—
Muehlenbeckia cunninghamii (Meissn.) F. Muell.	+	—	—
Rumex crystallinus Lange	+	—	—
* *R. acetosella* L.	+	—	+
CHENOPODIACEAE			
Rhagodia spinescens R.Br.	+	—	—
R. nutans R.Br.	+	+	+
Chenopodium album L.	+	+	+
C. pumilio R.Br.	+	+	+
Atriplex semibaccata R.Br.	+	+	+
A. muelleri Benth.	—	—	+
Bassia uniflora (R.Br.) F. Muell.	+	+	+
Kochia brevifolia R.Br.	+	+	+
K. pentagona R. H. Anderson	+	—	—
Enchylaena tomentosa R.Br.	+	+	+
Salsola kali L.	+	+	+
AMARANTHACEAE			
Alternanthera denticulata R.Br.	+	—	—
PORTULACACEAE			
Portulaca oleracea L.	+	—	+
RANUNCULACEAE			
Clematis microphylla DC.	—	+	—
LAURACEAE			
Cassytha melantha R.Br.	—	+	—
PAPAVERACEAE			
* *Papaver hybridum* L.	—	+	+
* *Fumaria micrantha* Lag.	—	+	+
CRUCIFERAE			
* *Brassica tournefortii* Gouan	—	+	+
* *Sisymbrium orientale* L.	+	+	+
* *Raphanus raphanistrum* L.	—	—	+
PITTOSPORACEAE			
Pittosporum phillyreoides DC.	—	+	+
Bursaria spinosa Cav.	—	—	+
Billardiera cymosa F. Muell.	—	+	—
LEGUMINOSAE			
Acacia acinacea Lindl.	—	+	+
A. microcarpa F. Muell.	—	+	+
A. ligulata A. Cunn. ex Benth.	+	—	+
A. hakeoides A. Cunn. ex Benth.	—	+	—
A. pycantha Benth.	—	+	+
A. lineolata Benth.	—	+	+
A. oswaldii F. Muell.	+	—	+
Cassia nemophila A. Cunn. ex Vog.	—	+	+
C. sturtii R.Br.	+	—	+
* *Medicago minima* (L.) L.	+	+	+
* *M. truncatulata* J. Gaertn. (syn. *M. tribuloides* Desr.)	+	+	+
* *M. sativa* L.	—	+	+
* *M. polymorpha* L. var. *ciliaris* (Ser.) Shinners	—	+	+
* *M. polymorpha* L. var. *polymorpha* (syn. *M. denticulata* Willd.)	+	+	+
* *M. scutellata* (L.) Mill.	—	+	—
* *M. littoralis* Rhode.	—	+	—
* *M. minima* (L.) L.	+	+	+
* *Melilotus indica* (L.) All.	—	+	+
Templetonia sulcata (Meissn.) Benth.	—	—	+
Swainsona procumbens (F. Muell.) F. Muell.	—	—	+
S. swainsonioides (Benth.) A. T. Lee	—	—	+
* *Vicia sativa* L.	—	+	—

APPENDIX 2—*continued*

	1	2	3
OXALIDACEAE			
Oxalis corniculata L.	−	+	+
O. pes-caprae L.	−	+	+
GERANIACEAE			
* *Erodium cicutarium* (L.) Ait.	+	+	+
* *E. crinitum* R. C. Carolin	+	+	+
ZYGOPHYLLACEAE			
Zygophyllum glaucum F. Muell.	−	+	+
EUPHORBIACEAE			
Euphorbia drummondii Boiss.	−	+	+
MALVACEAE			
Lavatera plebeia Sims	+	+	+
Sida corrugata Lindl.	−	+	+
MYRTACEAE			
Eucalyptus incrassata Labill.	−	+	−
E. dumosa A. Cunn. ex Schauer	−	+	+
E. oleosa F. Muell. ex Miq.	−	+	+
E. gracilis F. Muell.	−	+	−
E. calycogona Turcz.	−	+	+
E. viridis R. T. Baker	−	+	−
E. largiflorens F. Muell.	+	−	+
E. foecunda Schau.	−	+	−
E. behriana F. Muell.	−	−	+
Melaleuca uncinata R.Br.	−	+	−
M. pubescens Schauer	−	+	−
ONAGRACEAE			
Oenothera stricta Ledeb.	−	+	−
PRIMULACEAE			
* *Anagallis arvensis* L.	−	+	−
CONVOLVULACEAE			
Convolvulus erubescens Sims	+	+	+
* *C. arvensis* L.	−	+	+
BORAGINACEAE			
Halgania lavandulacea Endl.	−	+	−
Heliotropium europaeum L.	+	+	+
* *Amsinckia hispida* (Ruiz. and Pav.) Johnst.	−	+	+
* *A. lycopsoides* Lehm.	−	+	−
* *Lithospermum arvense* L.	+	+	+
LABIATAE			
* *Marrubium vulgare* L.	−	+	+
* *Lamium amplexicaule* L.	+	+	+
SOLANACEAE			
* *Lycium ferrocissimum* Miers	−	+	+
Solanum nigrum L.	+	+	+
S. simile F. Muell.	−	−	+
S. esuriale Lindl.	+	+	+
* *Datura stramonium* L.	+	−	−
MYOPORACEAE			
Myoporum platycarpum R.Br.	+	+	+
M. montanum R.Br.	−	−	+
M. deserti A. Cunn. ex Benth.	−	+	+
Eremophila longifolia (R.Br.) F. Muell.	+	−	+
PLANTAGINACEAE			
* *Plantago coronopus* L.	+	−	−
P. varia R. Br.	+	−	−
CURCURBITACEAE			
* *Cucumis myriocarpus* Naudin	+	+	+
* *Citrullus vulgaris* Schrad.	−	+	+

Appendix 2—*continued*

	1	2	3
Compositae			
Vittadinia triloba (Gaud.) DC.	+	+	+
Olearia ramulosa (Labill.) Benth.	—	+	—
Gnaphalium luteo-album L.	—	+	+
Helipterum corymbiflorum Schlechtendal	+	+	+
Helichrysum leucopsidium DC.	—	+	—
* *Inula graveolens* (L.) Desf.	+	+	+
* *Xanthium spinosum* L.	+	—	+
Senecio lautus Forst. f. ex Willd.	—	+	—
Centipeda cunninghamii (DC.) A. Br. & Aschers	+	—	—
* *Arctotheca calendula* (L.) Leyvns	—	+	—
* *Centaurea melitensis* L.	—	+	+
Microseris scapigera Forst. f. ex Sch. Bip.	+	—	—
* *Hedypnois cretica* (L.) Willd.	+	—	+
* *Hypochoeris radicata* L.	+	+	—
* *Scorzonera laciniata* L.	—	+	—
* *Picris echioides* L.	+	+	+
* *Chondrilla juncea* L.	—	+	+
* *Sonchus oleraceus* L.	+	+	+


b

AMPHIBIANS OF THE VICTORIAN MALLEE

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Abstract

The known anuran amphibian fauna of the Victorian Mallee consists of 12 taxa (11 species, one of which includes two call races). Available distributional data for the area are given for each form, together with associated field observations. Some broad zoogeographic patterns which are apparent in the frogs of this part of Victoria are briefly discussed.

Introduction

The only published information on the amphibians of the Victorian Mallee consists of four locality records for 3 species. The following account is based mainly on observations and collections which constitute part of a more general survey of the amphibians of SE. Australia. It should be pointed out that our knowledge of the amphibians of the Mallee is still at a very preliminary stage and that most of the available information concerns species composition and geographic distribution. A little is known about the general ecology of the Mallee frogs, but almost nothing about the problems of physiological adaptation by these species to the arid conditions of parts of the region.

For the present purposes the definition of the Mallee as used by Rawlinson (this volume) is followed, namely, that area of Victoria bounded in the north by the Murray R., in the west by the State border, in the east by longitude 144°E., and in the south by latitude 36° 30′ S.

All specimens examined are housed in the University of Melbourne, Zoology Department Collection. Literature records, where available, are given in the particular species accounts. Mating calls are reliable indicators of species identity and these were generally obtained by logging breeding choruses during night road traverses. Only localities additional to those where specimens were collected are listed in the sections on voice records (with the exception of the *Limnodynastes tasmaniensis* complex where two sibling call races are present). Specimens or voice records within a 5-mile radius of a town are generally included under the one locality (and the term 'area' added). Only those field observations made within the Mallee region are listed, but most of the literature references apply to the species in general.

Hylidae

Hyla aurea (Lesson)

Localities

Specimens: Lock No. 9, Murray R.; 3 miles E. of Mildura; L. Cullulleraine; 6 miles SE. of Red Cliffs; Carwarp; Nangiloc; Boundary Bend area; Nyah; Sea Lake; Wycheproof; 16 miles W. of Nhill; Kaniva.

Voice Records: Mildura; Annuello; L. Boga; 5 miles NW. of Dimboola; Wail; 15 miles W. of Kaniva.

Field Observations

The voice records were obtained during October. This species breeds in relatively permanent lakes, lagoons and dams. Males call while floating in open water.

Remarks

The populations of the Mallee are typical of the subspecies *raniformis* (Parker 1938). This subspecies has a wide distribution in SE. Australia, extending into the E. half of the Mallee and along the Murray R. valley into South Australia. A general account of the species is given by Moore (1961). Adult morphology and breeding biology of *H. aurea raniformis* are briefly described by Littlejohn (1963), and larval morphology by Martin (1965).

Hyla ewingi Duméril & Bibron

Localities

Specimens: None.

Voice Records: 2 miles S. of Serpentine.

Field Observation

Heard calling at the above locality during late October.

Remarks

Though very common to the south and south-east of the Mallee, *H. ewingi* barely reaches the SE. corner of the defined area. The adult morphology and breeding biology are briefly described by Littlejohn (1963), and larval morphology by Martin (1965). Geographic distribution, mating call structure, and relationship with *H. verreauxi* Duméril are discussed by Littlejohn (1965b).

Hyla peroni (Tschudi)

Localities

Specimens: 3 miles E. of Mildura; L. Cullulleraine; 2 miles N. of Nangiloc; Hattah Lakes; Nyah.

Voice Records: Lock No. 9, Murray R.; Mildura; 2 miles W. of Boundary Bend; Wemen; 2 miles S. of Serpentine.

Literature Record: Kerang (Copland 1957).

Field Observations

All voice records of this species were obtained during October. Males call from elevated positions in marginal or emergent vegetation of permanent lakes and lagoons.

Remarks

This species is restricted to the Murray R. valley and its associated drainage (Avoca and Loddon R.) in the Mallee. However, it has a more general distribution in E. Victoria (Littlejohn, Martin, & Rawlinson 1963) and E. New South Wales (Moore 1961). Moore (1961) gives a description of this species.

Leptodactylidae

Crinia parinsignifera Main

Localities

Specimens: Lock No. 9, Murray R.; L. Cullulleraine; Red Cliffs Pumps, Murray R.; 10 miles SE. of Robinvale; Hattah Lakes; Boundary Bend area; Durham Ox.

VOICE RECORDS: 5 miles W. of Lock No. 9, Murray R.; Mildura area; 6 miles SE. of Red Cliffs; Nangiloc; 18 miles W. of Boundary Bend; Boundary Bend; Wemen; Nyah West; 2 miles N. of Mystic Park; Kerang area; 9 miles S. of Kerang; 14 miles N. of Durham Ox; Wycheproof; 3 miles SW. of Boort; 6 miles S. of Durham Ox; 1 mile S. of Bears Lagoon; 2 miles S. of Warracknabeal; 17 miles E. of Nhill; Donald; 5 miles NW. of Dimboola.

LITERATURE RECORDS: L. Cullulleraine; Warracknabeal (Main 1957).

FIELD OBSERVATIONS

C. parinsignifera has been heard calling in late April, August, and October. Breeding sites range from shallow temporary roadside pools to the margins of permanent lakes and lagoons. Males call from the edges of ponds or from positions just above the water in emergent grasses.

REMARKS

This common species, which is wide-ranging farther east, is restricted to the N., E., and S. boundaries of the Mallee. Main (1957) gives some information on distribution and breeding biology. Mating call structure and calling behaviour have been discussed by Littlejohn (1958, 1959).

Crinia signifera Girard

LOCALITIES

SPECIMENS: 2 miles NW. of Wedderburn.

VOICE RECORDS: Nyah; L. Boga; 2 miles N. of Mystic Park; Kerang area; 9 miles S. of Kerang; 14 miles N. of Durham Ox; 8 miles N. of Durham Ox; Durham Ox; 3 miles SW. of Boort; 6 miles S. of Durham Ox; 1 mile S. of Bears Lagoon; 17 miles W. of Kaniva; Kaniva; 17 miles E. of Nhill; 5 miles NW. of Dimboola; Wail.

FIELD OBSERVATIONS

This species has been heard calling in late April, August, September, and October. Males call from the edges of temporary ponds.

REMARKS

The distribution of *C. signifera* in the Mallee is similar to that of *C. parinsignifera*, but is not as extensive along the Murray R. *C. signifera* is a common and wide-ranging species in SE. Australia. A general account of the *C. signifera* complex is given by Moore (1961). The adult morphology and breeding biology of *C. signifera* are discussed by Littlejohn (1958, 1959, 1963); there are also detailed considerations of mating call structure (Littlejohn 1958, 1959, 1964). Larval morphology and development are described by Martin (1965) and Littlejohn & Martin (1965a).

Limnodynastes dorsalis (Gray)

LOCALITIES

SPECIMENS: 6 miles SE. of Red Cliffs; Carwarp; Nangiloc; 10 miles N. of Hattah; 7 miles S. of Ouyen; 10 miles W. of Mittyack; Nyah; Nullawil; Wycheproof; Sea Lake; Kerang area; 17 miles W. of Kaniva; 2 miles S. of Serpentine.

VOICE RECORDS: Mildura area; Wemen; Annuello; Manangatang; 7 miles W. of Nyah; L. Boga; 16 miles N. of Culgoa; Culgoa; 2 and 7 miles S. of Warracknabeal; Donald; Kaniva; 5 miles NW. of Dimboola; Wail.

LITERATURE RECORD: L. Boga (Krefft 1866).

FIELD OBSERVATIONS

Calls of this species have been heard in March, August, September, and October. Egg masses were seen during March. Breeding sites are variable, ranging from large temporary ponds to fairly permanent lakes, lagoons, and dams. Males generally call from water, under cover of overhanging or emergent vegetation, but sometimes from the adjacent banks.

REMARKS

The populations of the Mallee may be assigned to the subspecies *dumerili* (Martin pers. comm.). *L. dorsalis* is a wide-ranging species through the S. and E. Mallee and along the Murray R. into South Australia. The taxonomy and general biology of the *L. dorsalis* complex is discussed by Moore (1961). There are also recent short accounts of breeding biology (Littlejohn 1963), larval morphology (Martin 1965), and mating call structure (subspecies *insularis*) (Littlejohn & Martin 1965c).

Limnodynastes fletcheri Boulenger

LOCALITIES

SPECIMENS: Lock No. 9, Murray R.; 3 miles E. of Mildura; L. Cullulleraine; Hattah Lakes; 5 miles W. of Boundary Bend.

VOICE RECORDS: Mildura; Nangiloc; 2 and 18 miles W. of Boundary Bend; L. Boga; Kerang area.

FIELD OBSERVATIONS

This species has been heard calling in March and October, and two egg masses were collected in late October. Males call from the water, supported and concealed by emergent vegetation. Breeding sites are large, fairly permanent bodies of water.

REMARKS

Within the Mallee this species is restricted to the Murray R. system. It is a characteristic frog of the other large rivers of the W. plains. The mating call, which has not been described elsewhere, is a soft, short single note with a quality similar to the bark of a distant dog. Moore (1961) discusses the morphology and distribution of this species.

Limnodynastes tasmaniensis Günther

Two allopatric call races (Northern and Southern) can be recognized within this species. The Northern Call Race ranges through SE. Queensland, E. New South Wales, and NE. Victoria, then along the Murray Valley into S. South Australia (Littlejohn unpub. obs.). This form has a mating call consisting of 2-5 short pulses which are rapidly repeated so that the sound has a staccato quality. Presumably, it was this call race which was studied by Moore (1961), for his description of the mating call agrees with that given above.

The Southern Call Race occurs mainly S. of the Dividing Range in Victoria (except in the W. part of the State), with an extension into SE. South Australia. It also occurs on Flinders Is. and Tasmania (Littlejohn & Martin 1965b). The mating call of the Southern Call Race is a single short pulse or 'click' (Littlejohn 1963) and has been described in detail by Littlejohn & Martin (1965c).

Where the geographic ranges of the two forms contact, zones of intergradation are produced, in which the individual frogs may be heard producing both single and multiple pulsed calls within the one calling sequence (Littlejohn unpub. obs.). Both forms occur in the Victorian Mallee and an intergrade zone runs along the E. boundary. Since the two call races cannot presently be recognized on external adult morphology, the specimens examined are grouped together; but voice records are separated into three categories: Northern Call Race, Southern Call Race, and Intergrades.

Localities

Specimens: L. Cullulleraine; Red Cliffs Pumps, Murray R.; Hattah Lakes; 10 miles SE. of Robinvale; 5 miles W. of Boundary Bend; Nyah; Sea Lake; 5 miles S. of Kerang; Wycheproof.

Voice Records:

Northern Call Race: Lock No. 9, Murray R.; Mildura; L. Cullulleraine; 6 miles SE. of Red Cliffs; Carwarp; Nangiloc; 2 and 18 miles W. of Boundary Bend; Wemen; Nyah.

Southern Call Race: Manangatang; 7 miles S. of Ouyen; Chinkapook; 4 miles E. of Chinkapook; 8 miles S. of Nandaly; 15 miles N. of Sea Lake; Sea Lake; 16 miles N. of Culgoa; Culgoa; 6 miles N. of Nullawil; Nullawil; 2 and 10 miles S. of Warracknabeal; 17 miles W. of Kaniva; Kaniva; 8 and 12 miles E. of Kaniva; 9 miles W. of Nhill; 17 miles E. of Nhill; 5 miles NW. of Dimboola.

Intergrades: Kerang area; 8 and 14 miles N. of Durham Ox; Durham Ox; 3 miles SW. of Boort; 2 miles S. of Serpentine.

Field Observations

Both races have been heard calling in March, August, September, and October. Eggs of the Southern Call Race were seen in late September. Breeding sites vary from river lagoons to temporary roadside ponds. Males call from the water, supported by emergent grasses.

Remarks

See the discussion in the introductory section for this species.

Neobatrachus centralis (Parker)

Localities

Specimens: 10 miles SE. of Underbool; 7 miles S. of Ouyen; 3 and 10 miles W. of Mittyack; Nandaly; 10 miles NW. of St Arnaud.

Voice Records: 8 miles S. of Nandaly; 9 miles W. of Nhill.

Field Observations

This species has been heard calling in March and August; recent egg masses were seen at the same time. *N. centralis* breeds in temporary ponds and dams. Males call while floating in open water.

Remarks

N. centralis appears to be the most arid-adapted of the species occurring in the Mallee and penetrates the drier parts of the continent, extending from the Mallee across to S. Western Australia (Main, Lee, & Littlejohn 1958). Littlejohn (1965a) has figured an audiospectrogram of the mating call of this species in Victoria, and the mating call of a Western Australian individual is described and figured by Littlejohn & Main (1959). Main (1965) gives a short description of the morphology and biology of *N. centralis* from S. Western Australia.

Neobatrachus pictus Peters

Localities

SPECIMENS: 7 miles S. of Ouyen; 4 miles S. of Culgoa; 10 miles NW. of St Arnaud.

VOICE RECORDS: 3 and 13 miles W. of Mittyack; Chinkapook; Nandaly; 8 miles S. of Nandaly; L. Boga area; Durham Ox.

Field Observations

Males have been heard calling in March and August, and fresh spawn was collected in March. Breeding sites are similar to those of *N. centralis* and males call while floating in open water.

Remarks

This species has an extensive E. and SW. distribution in SE. Australia and a large area of drier parts of the Mallee is included wthin its range. Moore (1961) gives a general description of the species, and Littlejohn (1963) has given a short account of adult morphology and breeding behaviour. An audiospectrogram of the mating call is figured by Littlejohn (1965a) and the larva is described by Martin (1965).

Pseudophryne bibroni Günther

Localities

SPECIMENS: None.

VOICE RECORDS: Durham Ox; 3 miles SW. of Boort; 6 miles S. of Durham Ox; 10 miles NW. of St Arnaud.

Field Observations

This species was heard calling in late April and early May.

Remarks

Specimens from adjacent localities (e.g. Koondrook, 9 miles N. of Bendigo, 5 miles N. of Glenorchy, and Mt Arapiles) are clearly assignable to *P. bibroni* so that there can be little doubt about the identification of the calls heard in the SE. Mallee. Mating calls of the three Victorian species of *Pseudophryne—bibroni, dendyi* Lucas, and *semimarmorata* Lucas—are very similar (Littlejohn 1963 and unpub. obs.), but the nearest known populations of another congeneric species are those of *P. semimarmorata* in the Grampians (unpub. obs.). A general account of *P. bibroni* is provided by Moore (1961); adult morphology and breeding biology are briefly described by Littlejohn (1963), and larval morphology by Martin (1965).

Discussion and Summary

Twelve taxa (11 species, one of which contains two call races) are known to occur in the Victorian Mallee as defined in the introduction. However, this number may be increased with more detailed collecting in the north-west, particularly following heavy summer rains.

Krefft (1866) lists *Hyla caerulea* (White) (as *Pelodryas caeruleus*) among the vertebrates of the lower Murray and Darling Rivers. No specific locality is given but the party was based at Gol Gol, New South Wales (opposite Mildura) for about nine months. Moore (1961) has summarized the known distribution of *H. caerulea* and lists specimens from the Darling R. (as Darling R. floods). We have not yet had any success in finding this species along the Murray R. and, for the present, must consider Krefft's record as referring to the Darling some distance above its junction with the Murray.

Three other species are listed by Krefft (1866) from the same general area, but again, no precise localities are given: *H. aurea* and *H. peroni* (already considered), and *Hyla adelaidensis* Gray. As we presently understand it, this latter species is restricted to Western Australia and it is not at all clear to which currently recognized SE. form his report can refer.

Two main zoogeographic patterns are evident in the distribution of Mallee frogs:

(1) The Murray R. valley is an important corridor for amphibians allowing 6 species to penetrate the otherwise inhospitable N. Mallee environment.

(2) Excluding the Murray R. valley, the Mallee represents a zone of subtraction from SE. (9 forms) to NW. (probably only one form, *N. centralis*). Presumably this is in response to the conditions imposed by the gradient of increasing aridity, which exerts a powerful influence on amphibian distribution.

Individual taxa may also be categorized and grouped into faunal components, of which five are recognizable:

(1) Central Australian—desert adapted forms which penetrate into the Mallee from the north-west. *N. centralis* clearly falls into this category as the only true desert species inhabiting the area.

(2) Riverine—forms restricted to the Murray R. valley and the larger rivers which cut across the Mallee and drain into the Murray. *H. peroni* and *L. fletcheri* are typical river frogs with this distributional pattern.

(3) Bassian—S. cool temperate adapted forms which penetrate into the Mallee from the south to varying degrees. *H. ewingi* and the Southern Call Race of *L. tasmaniensis* meet these requirements.

(4) Eyrean—SE. warm temperate adapted forms with ranges mainly N. and W. of the Dividing Range. *Crinia parinsignifera, L. dorsalis dumerili,* and *N. pictus* have these characteristics.

(5) Wide-ranging forms—the remaining taxa, *C. signifera, H. aurea raniformis,* and the Northern Call Race of *L. tasmaniensis* cannot be clearly assigned to any of the above categories because of their extensive distributions in SE. Australia.

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REPTILES OF THE VICTORIAN MALLEE

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Abstract

73 species of reptiles representing 9 families are recorded with specific locality data from the Victorian Mallee. None of these species is restricted to the area, and the Eyrean affinities of the reptile fauna are shown by comparison with the reptile faunas of (a) Gippsland (SE. Victoria; Bassian) and (b) S. Western Australia (Eyrean with some Bassian).

Introduction

In 1896, Spencer proposed a scheme which divided Australia into three faunal subregions, the Bassian, Eyrean, and Torresian. Subsequently, Serventy & Whittell (1951) added a fourth 'district', the South-Western, which was formed by the blending of Bassian and Eyrean elements in the south-west of Australia. These four divisions have gained recognition as the main faunal zones (or subregions) in Australia (Main, Lee, & Littlejohn 1958; Keast 1959) and may be defined as follows:

1. The Bassian subregion; a SE. coastal cool-temperate area with uniform seasonal rainfall.
2. The Torresian subregion; a NE. and N. coastal tropical area with summer maximum rainfall.
3. The South-Western subregion; a SW. coastal cool-temperate area with winter maximum rainfall.
4. The Eyrean subregion; the rest of the Australian continent, hot and with a low and irregular rainfall.

Although these faunal subregions are here defined areally, the terms are also used to refer to the biota of the respective areas.

Most of Victoria lies in the area which fits Spencer's Bassian subregion, but the Mallee lies within the Eyrean subregion. Thus, the Mallee district is an important faunal region when the distributions of Victorian animal species are being considered. In an attempt to determine whether the reptile fauna shows Eyrean affinities, comparisons are made with the faunas of (a) Gippsland, Victoria (Bassian) and (b) S. Western Australia (Eyrean with some Bassian).

The limits of the Victorian Mallee have been defined in at least three ways. Firstly there is the botanical boundary (Blackburn 1964), secondly the 1944 Mallee regional boundary (Central Planning Authority 1952), and thirdly the Mallee district boundary as used throughout the ANZAAS book *Introducing Victoria* (Leeper 1955). None of these is entirely suitable for the present purposes since the reptile fauna of NW. Victoria is comparatively uniform and shows little dependence on vegetation. Hence, somewhat arbitrary limits have been selected which include all three boundaries listed above. These limits are as follows: northern, the Victoria-New South Wales border (Murray R.); western, the Victoria-South Australia border; southern, latitude 36° 30′ S.; and eastern, longitude 144°E.

The list of species in this paper cannot be taken as a complete or final assessment, since the reptile fauna of the Mallee is very poorly known. Further field work in the area will almost certainly add more species to the list. As the fauna becomes better known, taxonomic changes are also to be expected. Specific locality records are given wherever possible as a first attempt at defining the distribution and abundance of species. These locality records are drawn from three main sources:

1. Specimens examined in the collection of the University of Melbourne Zoology Department, and the author's field records—such data are designated by (MUZD).
2. Specimens listed in the Reptile catalogue of the National Museum, Melbourne—such data are designated (NM).
3. References in the literature—such data are acknowledged to the original authors, e.g. (Worrell 1963).

The recent elapine generic name changes by Worrell (1961, 1963) have not gained any support to date, so to avoid further confusion the older, accepted, generic names (Kinghorn 1956) are used in this paper. Also, to standardize the spelling and taxonomy of the higher groups (families, etc.), the classification used by Romer (1956) has been adopted here.

CHELONIA

Chelyidae

Chelodina expansa Gray

Specimens examined (MUZD): L. Boga; Kerang.
Additional records (NM): Nil.
Literature: Murray R. and tributaries (Worrell 1963).

Chelodina longicollis (Shaw)

Specimens examined (MUZD): L. Cullulleraine; 1 mile E. of Merbein; Mildura; L. Boga; Kerang.
Additional records (NM): Nil.
Literature: Murray system (Worrell 1963).

Emydura macquarrii (Gray)

Specimens examined (MUZD): Red Cliffs; L. Boga; Kerang.
Additional records (NM): Nil.
Literature: Murray-Darling system (McCoy 1885 as *Chelmys macquaria*); large river systems of the Murray, Murrumbidgee, and Macquarie R. (Worrell 1963).

SQUAMATA

Lacertilia

Agamidae

Amphibolurus adelaidensis (Gray)

Specimens examined (MUZD): Nil.
Additional records (NM): Dimboola.
Literature: Dimboola (Lucas & Frost 1893).

Amphibolurus decresii (Duméril & Bibron)

Specimens examined (MUZD): Pine Plains, 15 miles W. of Patchewollock.
Additional records (NM): Nil.
Literature: Nil.

Amphibolurus barbatus (Cuvier)

Specimens examined (MUZD): 9 miles E. of Lock No. 9, Murray R.; 9 miles W. of Merbein; Mildura; Cullulleraine; Irymple; Meringur; Carwarp; 4 miles N. of Hattah; 2 miles NE. of Wemen; 9 miles W. of Wemen; 10 miles NW. of Annuello; 10 miles W. of Boundary Bend; 2 miles N. of Kiamil; 5 miles NW. of Piangil; 3 miles E. of Manangatang; Ouyen; Nyah; 6 miles SE. of Nyah; 5 miles NW. of Swan Hill; 6 miles NW. of Mystic Park; 1 mile S. of Kerang; 4 miles N. of Tempy; 6 miles NW. of Charlton.

Additional records (NM): Red Cliffs; Boyeo; Little Desert; Kewell.
Literature: Nil.

Amphibolurus maculatus (Gray)

Specimens examined (MUZD): Mildura; 4 miles N. of Hattah.
Additional records (NM): Red Cliffs.
Literature: Nil.

Amphibolurus muricatus (Shaw)

Specimens examined (MUZD): 5 miles N. of Hattah; Pine Plains, 15 miles W. of Patchewollock.
Additional records (NM): Hattah; Ouyen; Woomelang; Kiata.
Literature: Nil.

Amphibolurus pictus Peters

Specimens examined (MUZD): Mildura; Pine Plains, 15 miles W. of Patchewollock; 5 miles S. of Kiata.
Additional records (NM): Red Cliffs; Hattah; 5 miles N. of Sunset Tank; Ouyen; 30 miles S. of Murrayville; Nhill; Dimboola; Little Desert.
Literature: Murrayville (Barrett 1932); Dimboola (Lucas & Frost 1893).

Physignathus gilberti (Gray)

Specimens examined (MUZD): Nil.
Additional records (NM): Kurnwill near Werrimull.
Literature: Werrimull, NW. Vict. (Brazenor 1932).

Tympanocryptis lineata Peters

Specimens examined (MUZD): Nil.
Additional records (NM): Red Cliffs.
Literature: Mildura (Mitchell 1948).

GEKKONIDAE

Diplodactylus strophurus intermedius Ogilby

Specimens examined (MUZD): Nil.
Additional records (NM): Red Cliffs; Raak Plains; Ouyen; Chillingollah; Kewell; Nyang, Mallee, Vict.
Literature: NW. Victoria (Brazenor 1951); L. Albacutya (Lucas & Frost 1893 as *D. strophurus*); Kewell (Lucas & Frost 1893 as *D. strophurus*).

Diplodactylus tesselatus Günther

Specimens examined (MUZD): Nil.
Additional records (NM): Kewell; Mallee, Vict.
Literature: Dimboola (Lucas & Frost 1893); Kewell (Lucas & Frost 1893).

Diplodactylus vittatus Gray

Specimens examined (MUZD): Mildura.
Additional Records (NM): Ouyen; NW. Victoria.
Literature: Dimboola (Lucas & Frost 1893).

Gehyra variegata (Duméril & Bibron)

Specimens examined (MUZD): Mildura; 2 miles NE. of Wemen.
Additional records (NM): Werrimull; Red Cliffs; Mallee, Vict.
Literature: Murray R. between Swan Hill and Mildura (Lucas & Frost 1893).

Gymnodactylus milii (Bory)

Specimens examined (MUZD): Mt Korong, Wedderburn.
Additional records (NM): Meringur; Karawinna; Red Cliffs; Ouyen; Waitchie; L. Boga; Woomelang; Tittybong; Quambatook; Nyang, Vict.
Literature: Dimboola (Lucas & Frost 1893).

Heteronota binoei Gray

Specimens examined (MUZD): Mildura.
Additional records (NM): Mildura; Karawinna; Red Cliffs; Mallee, Vict.
Literature: Nil.

Lucasius damaeus (Lucas & Frost)

Specimens examined (MUZD): Nil.
Additional records (NM): Red Cliffs; Ouyen; Nyang, Mallee, Vict.
Literature: Nil.

Phyllodactylus marmoratus (Gray)

Specimens examined (MUZD): 4 miles W. of Lock No. 9, Murray R.; Mildura; Wycheproof; Fernihurst; Mt Korong, Wedderburn.
Additional records (NM): Karawinna; Red Cliffs; Kerang; Warracknabeal; Little Desert.
Literature: Dimboola (Lucas & Frost 1893).

Rhynchoedura ornata Günther

Specimens examined (MUZD): Nil.
Additional records (NM): Red Cliffs.
Literature: Nil.

PYGOPODIDAE

Aprasia pulchella Gray

Specimens examined (MUZD): Nil.
Additional records (NM): Mildura; L. Wallace; Ouyen.
Literature: Nil.

Delma fraseri Gray

Specimens examined (MUZD): Nil.
Additional records (NM): Karawinna; Narung; Hattah; Natya; Ouyen; Swan Hill; Woomelang; Kewell; Wedderburn.
Literature: Kewell (Lucas & Frost 1893).

Delma impar (Fischer)

Specimens examined (MUZD): L. Meering, 12 miles SW. of Kerang; Wycheproof.
Additional records (NM): Nil.
Literature: Nil.

Lialis burtonis Gray

Specimens examined (MUZD): Mildura; Koorlang; Woomelang.
Additional records (NM): Red Cliffs; Narung; Ouyen; Mallee, Vict.
Literature: Mallee scrub and warmer parts of Victoria (McCoy 1885).

Pygopus lepidopodus (Lacépède)

Specimens examined (MUZD): Rock Hole Bore, Sunset country.
Additional records (NM): Mildura; Yatpool; Ouyen; Wycheproof; Little Desert.
Literature: Kewell (Lucas & Frost 1893).

SCINCIDAE

Ablepharus boutonii (Desjardin)

Specimens examined (MUZD): Mildura.
Additional records (NM): Mildura; Irymple; Red Cliffs; Little Desert; Kewell.
Literature: Swan Hill (Lucas & Frost 1893); Dimboola (Lucas & Frost 1893).

Ablepharus greyii (Gray)

Specimens examined (MUZD): Mildura.
Additional records (NM): Red Cliffs; Pink Lakes, 35 miles W. of Ouyen; Ouyen; Chillingollah.
Literature: Nil.

Ablepharus lineatus (Bell)

Specimens examined (MUZD): Nil.
Additional records (NM): Mildura.
Literature: Nil.

Ablepharus lineoocellatus Duméril & Bibron

Specimens examined (MUZD): Lock No. 9, Murray R.; Mildura; Red Cliffs; 2 miles NE. of Wemen; 13 miles WNW. of Piangil; Manangatang; 8 miles N. of Underbool; Tutye; 10 miles W. of Patchewollock; 8 miles E. of Patchewollock; Rainbow; Kenmere; Wycheproof; 6 miles SE. of Wycheproof.
Additional records (NM): Pink Lakes; Ouyen; Dimboola; Kewell.
Literature: Dimboola (Lucas & Frost 1893).

Ablepharus timidus De Vis

Specimens examined (MUZD): Mildura; Locality outside Mallee—4 miles W. of Euston, N.S.W.
Additional records (NM): Mildura; Mallee, Vict.
Literature: Nil.

Egernia inornata Rosén

Specimens examined (MUZD): Locality outside Mallee—Renmark, S.A.
Additional records (NM): Hattah; 5 miles N. of Sunset Tank.
Literature: Nil.

Egernia kintorei Stirling & Zietz

Specimens examined (MUZD): Nil.
Additional records (NM): Nil.
Literature: Desert of N. Victoria (Worrell 1963).

Egernia striolata (Peters)

Specimens examined (MUZD): 4 miles W. of Lock No. 9, Murray R.; Red Cliffs.
Additional records (NM): Red Cliffs; L. Meran; Mallee, Vict.
Literature: Dimboola (Lucas & Frost 1893).

Egernia whiteii (Lacépède)

Specimens examined (MUZD): Nil.
Additional records (NM): Woomelang.
Literature: Nil.

Hemiergis decresiensis (Fitzinger)

Specimens examined (MUZD): Mt Korong, Wedderburn.
Additional records (NM): Mildura; Red Cliffs.
Literature: Nil.

Hemiergis peronii (Fitzinger)

Specimens examined (MUZD): Nil.
Additional records (NM): Mallee district, Victoria.
Literature: Nil.

Rhodona bipes Fischer

Specimens examined (MUZD): Nil.
Additional records (NM): NW. Victoria.
Literature: Nil.

Rhodona bougainvillii (Gray)

Specimens examined (MUZD): Rainbow.
Additional records (NM): Pink Lakes, 35 miles W. of Ouyen; Ouyen; Little Desert; Kewell.
Literature: Nil.

Rhodona punctovittata Günther

Specimens examined (MUZD): 10 miles W. of Patchewollock; locality outside Mallee—Wentworth, N.S.W.
Additional records (NM): Mildura; Irymple; Karawinna; Red Cliffs; Pink Lakes, 35 miles W. of Ouyen; Ouyen; Woomelang.
Literature: Swan Hill (McCoy 1885 as *R. officeri*); Swan Hill (Lucas & Frost 1893).

Sphenomorphus fasciolatus (Günther)

Specimens examined (MUZD): Nil.
Additional records (NM): Mildura.
Literature: Nil.

Sphenomorphus lesueurii (Duméril & Bibron)

Specimens examined (MUZD): Mildura; 4 miles N. of Hattah; Hattah; Mt Korong, Wedderburn.
Additional records (NM): Mildura; Red Cliffs; Ouyen.
Literature: Nil.

Sphenomorphus quoyii quoyii (Duméril & Bibron)

Specimens examined (MUZD): 4 miles W. of Lock No. 9, Murray R.
Additional records (NM): Nil.
Literature: Nil.

Sphenomorphus taeniolatus (Shaw)

Specimens examined (MUZD): Nil.
Additional records (NM): Irymple.
Literature: Nil.

Tiliqua occipitalis (Peters)

Specimens examined (MUZD): Kiata.

Additional records (NM): Red Cliffs; Ouyen.
Literature: N. Victoria (Mitchell 1950); Mallee, N. Victoria (Worrell 1963).

Tiliqua rugosa (Gray)

Specimens examined (MUZD): 2 miles W. of Lock No. 9, Murray R.; 10 miles E. of Lock No. 9, Murray R.; 6 miles W. of Merbein; 3 miles N. of L. Cullulleraine; 9 miles N. of Carwarp; 4 miles S. of Carwarp; 16 miles N. of Hattah; 1 mile S. of Bannerton; 9 miles E. of Hattah; 4 miles W. of Wemen; 8 miles S. of Hattah; 1 mile NW. of Annuello; 1 mile N. of Kiamil; 10 miles N. of Underbool; 10 miles W. of Ouyen; Walpeup; 20 miles E. of Manangatang; 10 miles SSE. of Ouyen; Tutye; 8 miles E. of Patchewollock; 1 mile S. of Tempy; 4 miles SSE. of Turriff.
Additional records (NM): Ouyen; Nhill; Little Desert; Kewell.
Literature: Murrayville (Barrett 1926 as *Trachysaurus rugosus*); Kewell (Lucas & Frost 1893 as *Trachysaurus rugosus*); Kewell (McCoy 1885 as *Trachysaurus rugosus*).

Tiliqua scincoides (Shaw)

Specimens examined (MUZD): Kerang.
Additional records (NM): Nil.
Literature: Nil.

VARANIDAE

Varanus gouldii (Gray)

Specimens examined (MUZD): 10 miles S. of Mildura; Carwarp; 5 miles N. of Hattah; Manangatang; 1 mile NW. of Nyah; 8 miles N. of Tempy.
Additional records (NM): Karawinna; Ouyen.
Literature: Kewell (McCoy 1885 as *Monitor gouldii*).

Varanus varius (Shaw)

Specimens examined (MUZD): 10 miles NW. of Annuello; Wycheproof.
Additional records (NM): Liparoo.
Literature: Warmer parts (of Victoria) on the Murray Plains (McCoy 1885 as *Hydrosaurus varius*).

OPHIDIA

BOIDAE

Morelia argus variegata Gray

Specimens examined (MUZD): Locality outside Mallee—Renmark, S.A.
Additional records (NM): Mildura; Kerang; Murray R., Vict.
Literature: N. Murray boundary (of Victoria) (McCoy 1885).

ELAPIDAE

Acanthophis antarcticus (Shaw)

Specimens examined (MUZD): Nil.
Additional records (NM): Banks of Murray, Victoria.
Literature: L. Boga (Krefft 1863); hot tracts (in Victoria) near the Murray (McCoy 1885).

Brachyaspis curta (Schlegel)

Specimens examined (MUZD): 10 miles S. of Kiata.
Additional records (NM): Kiata; Mallee, Vict.
Literature: Nil.

Brachyurophis australis (Krefft)

Specimens examined (MUZD): Nil.
Additional records (NM): Vinifera; Tempy; Speed; Tarnt; Woomelang.
Literature: Mallee, NW. Victoria (Kershaw 1917).

Demansia nuchalis (Günther)

Specimens examined (MUZD): Locality outside Mallee—Renmark, S.A.
Additional records (NM): Junction of Murray and Darling R.; Irymple; Red Cliffs; Hattah; Nyang.
Literature: NW. of Victoria (Worrell 1963).

Demansia psammophis (Schlegel)

Specimens examined (MUZD): Nil.
Additional records (NM): Red Cliffs.
Literature: Nil.

Demansia textilis (Duméril & Bibron)

Specimens examined (MUZD): Lock No. 9, Murray R.; 10 miles W. of Boundary Bend; 6 miles ESE. of Boundary Bend; 5 miles E. of Hattah; Torrita; 1 mile NW. of Nyah; 5 miles NW. of Swan Hill; 2 miles NW. of Mystic Park; Wycheproof.
Additional records (NM): Mildura; Irymple; Red Cliffs; Kulkyne; Natya; Ouyen; Cowangie; Swan Hill; Hopetoun; Rosebery; Kaniva; Kiata; Dimboola; Kewell; Cow Plains, Mallee, Vict.; Nyang station via Balpool.
Literature: Nil.

Denisonia devisi Waite & Longman

Specimens examined (MUZD): Nil.
Additional records (NM): Nil.
Literature: Junction of the Murray and Darling R. (Worrell 1963).

Denisonia flagellum (McCoy)

Specimens examined (MUZD): Nil.
Additional records (NM): Mallee, Vict.
Literature: Nil.

Denisonia gouldii (Gray)

Specimens examined (MUZD): Nil.
Additional records (NM): Ouyen; Sea Lake; Kewell; Mallee, Vict.
Literature: Nil.

Denisonia nigrostriata (Krefft)

Specimens examined (MUZD): Nil.
Additional records (NM): Ouyen.
Literature: NW. Victoria (Kershaw 1917); NW. Victoria (Mitchell 1951).

Denisonia suta (Peters)

Specimens examined (MUZD): L. Meering, 12 miles SW. of Kerang.
Additional records (NM): Mallee, Vict.
Literature: Nil.

Notechis scutatus (Peters)

Specimens examined (MUZD): Mildura; Kerang.
Additional records (NM): Junction of Murray and Darling R.; Mallee, Vict.
Literature: Murray R. district (Worrell 1963).

Oxyuranus scutellatus (Peters)

Specimens examined (MUZD): Nil.
Additional records (NM): Junction of the Murray and Darling R.
Literature: Junction of Murray and Darling (McCoy 1889 as *Diemenia microlepidotus*); N. Victoria (Boulenger 1896 as *Pseudechis microlepidotus*); N. Victoria (Waite 1929 as *Pseudechis microlepidotus*); N. Victoria (Mitchell 1950 as *Pseudechis microlepidotus*); Along the Darling from Bourke to the junction of the Murray and the Darling (Kinghorn 1956 as *Parademansia microlepidotus*); Junction of the Murray and Darling (Worrell 1963).

Pseudechis australis (Gray)

Specimens examined (MUZD): Locality outside Mallee—Renmark, S.A.
Additional records (NM): Nil.
Literature: Kewell (McCoy 1885); far inland all states except Tasmania (Worrell 1963).

Pseudechis porphyriacus (Shaw)

Specimens examined (MUZD): Mildura; Kerang.
Additional records (NM): Nil.
Literature: Murray R. (Worrell 1963).

Vermicella annulata (Gray)

Specimens examined (MUZD): Nil.
Additional records (NM): Meringur; Red Cliffs; Hattah; Ouyen; Patchewollock; Woomelang; Kerang; Nhill.
Literature: Patchewollock (Kershaw 1917 as *Furina occipitalis*).

TYPHLOPIDAE

Typhlops australis (Gray)

Specimens examined (MUZD): Nil.
Additional records (NM): Ouyen; Beulah; Mallee, Vict.
Literature: Southern Australia—Hopetoun area, Birchip area, Ouyen area (Waite 1918).

Typhlops bituberculatus (Peters)

Specimens examined (MUZD): Wyperfeld; Rainbow; Barrapoort.
Additional records (NM): Mildura; Carwarp; Ouyen; Woomelang; Beulah; Nhill; Gerang; Myall via Koondrook.
Literature: All Australia, abundant in south—Hopetoun area, Birchip area, Ouyen area, Ultima area (Waite 1918).

Typhlops broomi Boulenger

Specimens examined (MUZD): Nil.
Additional records (NM): Nil.
Literature: Mallee, Victoria—Hopetoun area (Waite 1918).

Typhlops ligatus Peters

Specimens examined (MUZD): Nil.
Additional records (NM): Mallee, Vict.
Literature: Victoria—Underbool area (Waite 1918).

Typhlops nigrescens (Gray)

Specimens examined (MUZD): Nil.

Additional records (NM): Mildura; Irymple; Robinvale; Woomelang; Donald; Kewell.
Literature: Victoria—Hopetoun area (Waite 1918).

Typhlops pinguis Waite

Specimens examined (MUZD): Nil.
Additional records (NM): Pink Lakes, 35 miles W. of Ouyen.
Literature: Mallee, Victoria—Hopetoun area (Waite 1918).

Typhlops proximus Waite

Specimens examined (MUZD): Nil.
Additional records (NM): Charlton; Mallee, Vict.
Literature: N. Victoria—Mildura area, Hopetoun area, Kerang area (Waite 1918).

Typhlops unguirostris Peters

Specimens examined (MUZD): Nil.
Additional records (NM): Mallee, Vict.
Literature: Mallee, Victoria—Hopetoun area (Waite 1918).

Discussion

In this paper 73 species of reptiles representing 34 genera and 9 families are recorded from the Victorian Mallee. None of the 73 species is restricted to this area and most also occur extensively in the desert and semi-desert regions of Australia. The Mallee reptile fauna therefore shows no endemism and the Mallee cannot be considered as a separate faunal division.

As has already been pointed out, most of Victoria lies in Spencer's (1896) Bassian zoogeographic subregion, but the Mallee lies in the Eyrean subregion. Thus, if Spencer's scheme applies to the reptiles, and Keast (1959) has already suggested that it could, the Mallee reptile fauna would be Eyrean in nature.

In order to determine the affinities of the Mallee reptile fauna, it is compared to that of two other areas. Firstly, the Mallee reptile fauna is compared with that of a typical Bassian area: Gippsland, a SE. Victorian district of approximately the

TABLE 1

Comparison of Mallee and Gippsland Reptile Faunas

Family	Number of Species in the Mallee	Number of Species in Gippsland	Number of Shared Species
CHELONIA			
CHELYIDAE	3	1	1
LACERTILIA			
AGAMIDAE	8	3	1
GEKKONIDAE	9	–	–
PYGOPODIDAE	5	–	–
SCINCIDAE	21	19	4
VARANIDAE	2	1	1
OPHIDIA			
BOIDAE	1	–	–
ELAPIDAE	16	7	3
TYPHLOPIDAE	8	–	–
TOTAL	73	31	10

same size as the Mallee (Leeper 1955). Data on Gippsland reptiles were obtained from the University of Melbourne Zoology Department collection and the author's field records. Secondly, the Mallee reptile fauna is compared with that of a predominantly Eyrean area: S. Western Australia. This was taken as the area of Western Australia S. of a line passing E.-W. through Geraldton. It is not an ideal area for listing Eyrean species as it includes Serventy & Whittell's (1951) South-Western subregion with some Bassian elements; however, it is the only suitable region with a reasonably complete reptilian fauna list (Glauert 1957, 1961; Worrell 1963). The size of the Bassian component in the South-Western subregion is demonstrated by a comparison of the reptile faunas of Gippsland and S. Western Australia.

Faunal Relationships of the Victorian Mallee and Gippsland

There are only 31 species of reptiles in Gippsland (Table 1). 10 of these species are shared with the Mallee which has 73 species. The shared species are:

C. longicollis, A. muricatus, E. whiteii, H. decresiensis, R. bougainvillii, T. scincoides, V. varius, D. textilis, N. scutatus, P. porphyriacus. 4 of these species, *C. longicollis, T. scincoides, N. scutatus,* and *P. porphyriacus,* are associated exclusively with the Murray R. in the Mallee region.

16 genera of reptiles occur in Gippsland and 13 are shared with the Mallee which has 34 genera (Table 4). The shared genera are:

Chelodina, Amphibolurus, Physignathus, Egernia, Hemiergis, Rhodona, Sphenomorphus, Tiliqua, Varanus, Demansia, Denisonia, Notechis, Pseudechis. The scincid genus *Leiolopisma*, which has 8 species in Gippsland, is unrepresented in the Mallee. Conversely, the scincid genus *Ablepharus*, which has 5 species in the Mallee, is unrepresented in Gippsland.

5 families of reptiles occur in Gippsland and all are shared with the Mallee (Table 1). However, another 4 families of reptiles, the *Gekkonidae, Pygopodidae, Boidae*, and *Typhlopidae*, which are represented in the Mallee by 9, 5, 1 and 8 species respectively, are absent from Gippsland.

Table 2

Comparison of Mallee and S. Western Australian Reptile Faunas

Family	Number of Species in the Mallee	Number of Species in S. Western Australia	Number of Shared Species
CHELONIA			
Chelyidae	3	3	–
LACERTILIA			
Agamidae	8	15	7
Gekkonidae	9	16	8
Pygopodidae	5	10	4
Scincidae	21	45	15
Varanidae	2	5	1
OPHIDIA			
Boidae	1	3	1
Elapidae	16	21	9
Typhlopidae	8	11	4
TOTAL	73	129	49

In summary, it can be seen that only 14% of the species, 38% of the genera, and 56% of the families of reptiles in the Mallee also occur in Gippsland (Table 4). This indicates that there is a striking difference between the faunas of these two areas, even though they are only separated by about 200 miles.

Faunal Relationships of the Victorian Mallee and Southern Western Australia

As mentioned earlier, S. Western Australia includes Serventy & Whittell's (1951) South-Western subregion with Eyrean and Bassian elements. Thus, before comparing the Mallee reptile fauna to that of S. Western Australia, the size of the Bassian component must be measured. This can best be done by comparing the Gippsland reptile fauna (Bassian) with that of S. Western Australia at the specific level.

6 species of reptiles are shared between Gippsland and S. Western Australia (Table 3). The shared species are:

A. muricatus, E. whiteii, L. metallicum, L. trilineatum, D. coronoides, N. scutatus.

These species may be considered as Bassian forms on the basis of their general distributions (Keast 1959, Rawlinson unpublished). Thus, at most, only 6 of the 129 species of reptiles in S. Western Australia are Bassian forms. As this is less than 5% of the species, the S. Western Australian reptile fauna is clearly of a predominantly Eyrean nature.

Table 3

Comparison of Gippsland and S. Western Australian Reptile Faunas

Family	Number of Species in Gippsland	Number of Species in S. Western Australia	Number of Shared Species
CHELONIA			
Chelyidae	1	3	–
LACERTILIA			
Agamidae	3	15	1
Gekkonidae	–	16	–
Pygopodidae	–	10	–
Scincidae	19	45	3
Varanidae	1	5	–
OPHIDIA			
Boidae	–	3	–
Elapidae	7	21	2
Typhlopidae	–	11	–
TOTAL	31	129	6

There are 129 species of reptiles in S. Western Australia (Table 2). 49 of these species are shared with the Mallee which has 73 species. The shared species are:

A. adelaidensis, A. barbatus, A. decresii, A. maculatus, A. muricatus, A. pictus, T. lineata, D. strophurus, D. vittatus, G. variegata, G. milii, H. binoei, L. damaeus, P. marmoratus, R. ornata, A. pulchella, D. fraseri, L. burtonis, P. lepidopodus, A. boutonii, A. greyii, A. lineatus, A. lineoocellatus, A. timidus, E. inornata, E. kintorei, E. whiteii, H. peronii, R. bipes, S. fasciolatus, S.

lesueurii, S. taeniolatus, T. occipitalis, T. rugosa, V. gouldii, M. argus variegata, A. antarcticus, B. curta, D. nuchalis, D. psammophis, D. gouldii, D. suta, N. scutatus, P. australis, V. annulata, T. australis, T. bituberculatus, T. broomi, T. pinguis. 3 of these species *A. muricatus, E. whiteii,* and *N. scutatus* are also shared with Gippsland.

44 genera of reptiles occur in S. Western Australia and 32 are shared with the Mallee which has 34 genera (Table 4). This shared genera are:

Chelodina, Amphibolurus, Physignathus, Tympanocryptis, Diplodactylus, Gehyra, Gymnodactylus, Heteronota, Lucasius, Phyllodactylus, Rhynchoedura, Aprasia, Delma, Lialis, Pygopus, Ablepharus, Egernia, Hemiergis, Rhodona, Sphenomorphus, Tiliqua, Varanus, Morelia, Acanthophis, Brachyaspis, Brachyurophis, Demansia, Denisonia, Notechis, Pseudechis, Vermicella, Typhlops. The scincid genus *Ablepharus* is represented in S. Western Australia by 7 species including the 5 forms present in the Mallee. This contrasts with the situation in Gippsland where the genus is unrepresented. The scincid genus *Leiolopisma* is also represented in S. Western Australia but the only 2 species (*L. metallicum* and *L. trilineatum*) are both Bassian intrusives in the South-Western subregion (see earlier).

S. Western Australia and the Mallee contain the same 9 families (Table 2). The 4 families *Gekkonidae, Pygopodidae, Boidae,* and *Typhlopidae,* which are not represented in Gippsland, are well represented in S. Western Australia, and share many species with the Mallee.

In summary, it can be seen that 67% of the species, 94% of the genera, and 100% of the families of reptiles in the Mallee also occur in S. Western Australia (Table 4). Thus, there are great similarities between the reptile faunas of these two areas even though they are separated by at least 800 miles.

TABLE 4

Summary of the similarities of the reptile fauna of the Mallee with those of S. Western Australia and Gippsland at the specific, generic, and family levels

Taxa		Number in the Mallee	Number shared with S. Western Australia	Number shared with Gippsland
Species	No.	73	49 (129)	10 (31)
	%	100	67	14
Genera	No.	34	32 (44)	13 (16)
	%	100	94	38
Families	No.	9	9 (9)	5 (5)
	%	100	100	56

Total numbers for S. Western Australia and Gippsland in parentheses

Conclusions

From the preceding discussion and Table 4 three conclusions are evident:

1. The Victorian Mallee reptile fauna is distinct from that of the Gippsland region, even though the regions are of approximately the same area and are only separated by about 200 miles.
2. The Victorian Mallee reptile fauna is very similar to that of S. Western Australia, although the regions are separated by over 800 miles.

3. Although there is only a small degree of similarity between the reptile faunas of Gippsland and S. Western Australia, this nevertheless supports the suggestion of Main et al. (1958) that there was an earlier faunal connection between these two regions.

These conclusions are consistent with placing the Victorian Mallee into Spencer's (1896) Eyrean subregion and Gippsland into the Bassian subregion. Also, as has already been recorded by Keast (1959), the occurrence of 6 Bassian (Gippsland) reptile species in S. Western Australia supports Serventy & Whittell's (1951) idea that the South-Western subregion is a blending of Bassian and Eyrean elements, with the Eyrean components predominating.

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HONEYEATERS OF THE SUNSET COUNTRY

By N. J. Favaloro
Mildura, Vict.

In the far NW. corner of Victoria there are still extensive tracts of Mallee in their virgin state. Nevertheless, these are only remnants of what was originally a vast area known locally as 'The Sunset'. The exact boundaries were somewhat indefinite but, for the purposes of this discussion, it can be regarded as having been bounded on the north by what is now the Sturt Highway and on the south by the Ouyen Highway, while it extended from the 142 meridian in the east to the South Australian border in the west.

During the last 45 years serious inroads have resulted from closer settlement, particularly in the north where the present boundary of the Sunset is at least 20 miles S. of the Sturt Highway, and in the south where an irregular and less well-defined boundary is now some 12 to 15 miles to the north of the Ouyen Highway. Cultivation and clearing of the Mallee along the E. and the W. edges of the Sunset have been less severe but none the less persistent and relentless.

Until comparatively recent times, the remainder of the Sunset has been regarded by the public generally as useless, and little or no interest had been taken in it by State Departmental bodies. With the awakening of public interest and the growing demand for more and more land to be opened up for grazing and pastoral purposes, it behoves all those interested in Natural History and the preservation of natural habitats to plan now for adequate reservations throughout the Sunset.

The greatest danger, apart from the complete and final destruction of habitats by clearing, is fire. Unfortunately, when outbreaks do occur, they are usually ignored and nothing is done to prevent or control the blaze until private property or crops are endangered. In the meantime, valuable timber is lost, rare fauna and flora suffer irreparable damage, and unique habitats are destroyed.

The loss of habitats is indeed serious, as it threatens the very existence of such indigenous birds and mammals as are fortunate enough to survive in the small pockets of scrub which escape the fire. Unfortunately, owing to the low rainfall and sand drifts, regeneration is painfully slow.

Three large and extensive fires in the Sunset over the past five years have had disastrous effects and should be taken as a serious warning of what can happen in the future.

The Sunset supports an amazing variety of species ranging from the Emu, *Dromaius novae-hollandiae*, and the Mallee Fowl, *Leipoa ocellata*, on the one hand to the diminutive Mallee Emu-Wren, *Stipiturus mallee*, on the other. In the open forests where large timber and belts of pine and belar flourish, parrots and cockatoos are well represented. They too are being adversely affected, not only by loss of habitat resulting from clearing, but also because their breeding hollows are destroyed by timber men and wood-cutters from year to year. Birds of prey, both diurnal and nocturnal, inhabit suitably timbered flats and ridges which occur throughout the area.

However, the main objective of this paper is to review the status of one family of birds occurring in the Sunset, namely the Honeyeaters and, as they belong to the most numerous and widely distributed group of birds on the Australian continent, it is not surprising that so many varied forms have been recorded from this comparatively small and restricted section of the Mallee. Of the 69 species recognized in the *Checklist of the Royal Australasian Ornithologists' Union* (1926 ed.), 34 have been recorded in the State of Victoria and, of these, no less than 18 have also been recorded from the Sunset. It is interesting to note in passing that all of these species, except one, have been known to breed in the Sunset. The 18 species to which I refer are as follows:

578 *Melithreptus lunatus*—White-naped Honeyeater
583 *M. brevirostris*—Brown-headed Honeyeater
585 *Plectorhyncha lanceolata*—Striped Honeyeater
589 *Myzomela nigra*—Black Honeyeater
593 *Gliciphila melanops*—Tawny-crowned Honeyeater
594 *G. albifrons*—White-fronted Honeyeater
602 *Certhionyx variegatus*—Pied Honeyeater
608 *Meliphaga virescens*—Singing Honeyeater
617 *M. leucotis*—White-eared Honeyeater
620 *M. cratitia*—Purple-gaped Honeyeater
622 *M. ornata*—Yellow-plumed Honeyeater
623 *M. plumula*—Yellow-fronted Honeyeater
625 *M. penicillata*—White-plumed Honeyeater
631 *Meliornis novae-hollandiae*—Yellow-winged Honeyeater
635 *Myzantha flavigula*—Yellow-throated Miner
636 *Myzantha obscura* = *Melanotus*—Dusky Miner
638 *Anthochaera carunculata*—Red Wattle-Bird
640 *Acanthagenys rufogularis*—Spiny-cheeked Honeyeater

There are two other species reputed to have occurred in the Sunset but, although I shall record them on the authority of A. G. Campbell, I think they can only be listed tentatively pending confirmation, viz.:

Grantiella picta—Painted Honeyeater
Myzantha melanocephala—Noisy Miner

The Painted Honeyeater has an interesting distribution, taking in the greater part of New South Wales to the east of the Darling R., and extending in Victoria to the N. central sector of the State, the W. plains and to the north-east of Melbourne, but it appears to miss the Mallee in the north-west.

The general distribution of the Noisy Miner, on the other hand, would suggest this species as a more likely candidate for inclusion in a list of Sunset Honeyeaters, but I have yet to find a suitable habitat for *M. melanocephala* within the defined area, and Campbell's record appears to be based on a record from Pine Plains, at least 30 miles to the south of the Sunset.

Having regard to the highly developed migratory characteristics of most species of Honeyeaters, it is not surprising that there is considerable variation in the numerical strength of the various species from time to time, and in the number of species themselves inhabiting the area at any particular time.

Residential species are few and residential individuals even fewer, as the populations of the various species change with the rise and fall of the intensity of migratory movements.

The White-eared Honeyeater, *M. leucotis*, is undoubtedly the outstanding example of residential groups, as the individuals themselves are residents in the strictest sense of the term. They inhabit the same fixed territory from year to year and the breeding pairs usually build their nests within a defined and rather restricted area each season. Their numbers, too, are static and they appear to be unable to adapt themselves to changing conditions when their habitat is destroyed.

The genus *Meliphaga* to which they belong is strongly represented, accounting for one-third of the total species listed above. Natural permanent water is practically non-existent in the Sunset, but here and there bores, wells, and tanks have been constructed. In such environments, small groups of White-plumed Honeyeaters, *M. penicillata*, have become established and, although some birds are nearly always present, it is fairly safe to assume from their varying numbers that only a very small percentage, if any, are really permanent residents. But, so long as the water lasts, so do the White-plumed remain. In contrast with their more robust relative, the White-eared, which is fairly evenly distributed wherever low dense cover is available, the distribution of the White-plumed is broken and patchy.

It is over 50 years since the first Yellow-fronted Honeyeaters, *M. plumula*, were recorded from Victoria in the vicinity of Murrayville. In more recent times, however, they have become established as residents in the far W. sector of the Sunset, some 20 miles to the north-east of Pinnaroo. Some 10 years ago a pair was located by Mr Roy Ribbons and, since then, the colony has grown until at present there are at least 60 resident breeding pairs in the colony.

This is a hardy species of which there appear to be two major populations—one in the dry interior of the south-west of Western Australia and the other, separated by the Nullarbor Plain, covers most of South Australia and a small portion of the far NW. corner of New South Wales. There are only a few scattered records to the east of the Darling R., yet its closest affinities, *M. flavescens*, the Yellow-tinted Honeyeater, and *M. flava*, the Yellow Honeyeater, are virtually coastal forms, extending in the ease of the Yellow-tinted from the Fitzroy R. in the Kimberleys to Normanton on the Gulf of Carpentaria, and in the case of the Yellow Honeyeater, from the tip of Cape York to the Tropic of Capricorn.

It is interesting to observe the definite and comparable break in the distribution of these two species formed by the dry W. slopes of Cape York itself. Having observed all three species in the field, one cannot help but be impressed by the similarity of their appearance and their behaviour. Nevertheless, there is, even in this closely allied group within the genus, a remarkable difference in the eggs of these three species. Those of the Yellow-fronted more closely resemble typical sets of the Purple-gaped Honeyeater, *M. cratitia*, and the Yellow-tufted Honeyeater, *M. melanops*, and are usually two in number although three have occasionally been recorded. The eggs of the Yellow-tinted are smaller and of a paler pink. Of 13 nests taken by H. Barnard and General F. Hill for H. L. White on the McArthur R. in Northern Territory, 12 of them contained the full set of one egg only, the other being a set of two. On the other hand, the Yellow Honeyeater's clutch is almost invariably two and the eggs are among the most beautiful and easily distinguished eggs of all the Honeyeaters, being lavishly and boldly decorated with rich pink markings on a lighter and delicate pinkish base.

Another colony of Yellow-fronted Honeyeaters was recently located to the north-east of Panitya but, so far, it is not known whether or not it has become permanently established.

Of the remaining three members of *Meliphaga*, namely *virescens, cratitia,* and *ornata*, the Singing Honeyeater has the greatest range in so far as it occurs in the west and the drier portions of practically the whole of our continent, yet it is by no means plentiful in the Sunset, and shows a preference for the more open flats where isolated clumps of shrubs dot the landscape. Their eggs are of such a uniform pink that it is difficult at times to detect the presence of the egg of the Pallid

Cuckoo, *Cuculus pallidus*, when the nest of this Honeyeater has fallen a victim to the Cuckoo.

Throughout their entire range, the distribution of the Purple-gaped and the Yellow-plumed Honeyeaters is almost identical, but that of the latter is somewhat more extensive, especially in Western Australia. Although both species are virile migrants, seasonal movements and fluctuations in the numbers of *M. ornata* are much stronger than those of *M. cratitia.* In good seasons the Yellow-plumed Honeyeaters appear in flocks throughout the year. The Purple-gaped Honeyeater enjoys a more restricted local habitat and has never appeared in such vast numbers as the Yellow-plumed. No other genus in the Sunset is represented by more than two species.

The first of the three genera in which two species are represented is *Melithreptus.* It was not until September 1964 that the White-naped Honeyeater, *M. lunatus*, was first recorded in the far SW. corner of the Sunset by Mr Roy Ribbons. In company with Mr Ribbons and Mr H. Morton, I visited several sectors of the country to the north of Tutye and located many colonies, thus proving that the invasion was an extensive one. but the birds did not remain long and within the ensuing three weeks they had left the various districts visited by them. This is the only Honeyeater of the Sunset which does not breed within its confines.

Its co-gener, the Brown-headed Honeyeater, *M. brevirostris*, is a plain drab bird in comparison, and is so inconspicuous that it would often pass unnoticed but for its persistent rowdy and piercing call. It breeds throughout its range. The Brown-headed Honeyeaters are gregarious by nature and tend to congregate in small family flocks like all other members of the genus. They are too frequently chosen as foster parents by the Pallid Cuckoo.

The Tawny-crowned Honeyeater, *Gliciphila melanops*, and the White-fronted Honeyeater, *G. albifrons*, are the two representatives of the typical heath dwellers. Their appearances throughout the Mallee are sporadic so far as *melanops* is concerned but more of a seasonal event in the case of *albifrons*, the former usually occurring in restricted numbers, and the latter in great force when favourable conditions prevail.

Their habits, their calls, and their ecology in general is less varied than one finds in the various species of *Meliphaga*. The observer has no difficulty whatsoever in realizing that these two species are so closely related. Both lay eggs of a similar size and lacking in colour, being almost white with few markings. Their nesting sites are almost identical, as both species prefer to build in the top of a porcupine bush or low down at the base of a mallee shrub. Some years ago, I found a nest of *G. albifrons* which contained two fresh eggs of the Honeyeater and one of the Horsfield Bronze Cuckoo, *Chalcites basalis*.

The Yellow-throated Miner, *Myzantha flavigula*, is very plentiful throughout the Sunset and is found wherever big timber, pine, and belar still stand. It is the common Miner of the Mallee and is easily identified by the conspicuous white rump which can be seen at quite a considerable distance.

The other Miner of the Mallee, known as the Dusky Miner, *M. obscura*, has always been a comparatively rare bird. It should not be confused with another bird bearing the same name and being of Western Australian origin. The Dusky Miner of Western Australia and of Eyre Peninsula in South Australia is a subspecies of the Yellow-throated Miner. Despite the excellent work by Mr H. Condon in dealing with the nomenclature of these two species, some ornithologists still confuse them.

During the last 10 years, the numerical strength of the Dusky Miner in the Sunset has deteriorated alarmingly. Destruction of its habitat has had a disastrous effect upon its survival. Large areas of country N. from Underbool to Murrayville, where these birds were formerly plentiful, have been cleared. These Miners do not appear to have established thmselves on the Sunset fringes N. of the clearing, and they have disappeared entirely from many of their former territories N. of Panitya. The small breeding colony near the Hattah Lakes is now only a fraction of what it was in 1952.

In Victoria, the Dusky Miner is sharing with the Helmeted Honeyeater, *M. cassidix*, the doubtful distinction of being our rarest Honeyeater. Even outside the Sunset the habitat of *M. obscura* is very restricted and it is obvious that only prompt and constructive conservation of habitat can prevent further loss.

Identification in the field is simplified by the complete lack of the white rump which gives this bird the appearance of being uniform in colour from the nape of the neck almost down to the tip of the tail.

In Victoria, the Red Wattle Bird, *Anthochaera carunculata*, is so well known that further comment would seem unnecessary. It has adapted itself very well in the dry NW. corner of our State where it reaches the limit of its range in Victoria. During the breeding season their harsh raucous calls dominate all others in the more heavily timbered portions of the Mallee. In the springtime their numbers are greatly augmented but a small percentage remains throughout the autumn and winter periods. Their stick nests are usually built in open situations, varying from 2 ft to 12 ft from the ground, but occasionally a cleverly concealed nest may be hidden away in a clump of mistletoe or built in a thick cluster of young mallee shoots. Two eggs of rich salmon, boldly blotched, constitute the usual clutch, but one remarkable set of three was deposited in the hollowed-out top of the nest of a White-browed Babbler, *Pomatostomus superciliosus* at a height of 30 ft from the ground.

That was the only occasion on which I have ever recorded the Wattlebird usurping the nest of another species. Unfortunately this nest was deserted and when I visited it the following week the eggs had disappeared.

The remaining 4 Honeyeaters of the Sunset are the Black (*Myzomela nigra*), the Yellow-winged (*Meliornis novae-hollandiae*), the Spiny-cheeked (*Acanthagenys rufogularis*), and the Pied Honeyeater (*Certhionyx variegatus*). The first two are the sole representatives of their respective genera occurring in the Sunset and the latter two are monotypic.

The Black Honeyeater is by far the smallest of the Honeyeaters to visit NW. Victoria. They are regular annual migrants to the Sunset in small numbers, but at irregular intervals there are spectacular invasions when the birds arrive in considerable force. There are rarer instances when the migrating birds run into many thousands and, on these occasions, they invade the whole of N. Victoria.

Black Honeyeaters are quiet and somewhat secretive in their movements, being rather difficult to locate under normal circumstances. During the breeding season, however, they indulge in extensive display and the high pitched plaintive call of the male can be heard for a considerable distance. While he is calling and indulging in fancy acrobatic flights, the female is quietly and busily engaged either with nest building or brooding eggs and young. The migratory flights of Black Honeyeaters are probably nocturnal as I have never seen them arrive nor witnessed their departure.

Only a few favoured localities along the S. fringes of the Sunset to the north and the north-west of Cowangie are visited annually by a few pairs of Yellow-winged Honeyeaters, *M. novae-hollandiae*. Usually they begin nesting shortly after their arrival and depart again soon after they have reared their brood. They no doubt come from the south where they are more plentifully distributed in the Big and Little Desert country. During the autumn, single birds are likely to be seen wherever acacia and broom-bush flourish. It is rather an interesting characteristic of this particular species, especially as individual Yellow-wings are sometimes recorded in unexpected and sometimes most unlikely places in Victoria N. of the Great Divide.

Spiny-cheeked Honeyeaters, *A. rufogularis*, are affected less by habitat than many of the other species under consideration. They can and do adapt themselves to changing conditions and are still plentiful and thriving in districts where the most ruthless methods of clearing have been adopted. Their adaptability is undoubtedly assisted by their ability to make the best of any suitable breeding site available. They nest just as freely in a citrus or olive grove, in ornamental garden shrub or peppercorn, as they do in native mallee trees and shrubs.

The Pied Honeyeater, *C. variegatus*, is the rarest Honeyeater in the Sunset and is seldom recorded. The unique discovery of a breeding pair at Manya by W. Burgess on 7 October 1946 has never been repeated.

Although Honeyeaters generally are fond of nectar and are lovers of flowering gums and shrubs, they are nevertheless essentially insectivorous, and it is not until there are ample supplies of insects available for them that widespread breeding takes place.

Extensive areas are needed to support Honeyeaters, apart altogether from suitable breeding habitats, and every effort should be made to support those organizations interested in the preservation of substantial areas in their natural state in the Sunset. It is most desirable that several large compact areas should be set aside as reserves and active steps taken to deal promptly and effectively with ever-present fire hazards in particular.

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MAMMALS RECORDED FOR THE MALLEE, VICTORIA

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Abstract

The major vegetational formations of the Mallee are briefly discussed and sources of data about Mallee mammals are indicated. A list is given of 41 mammals recorded from in or near the Victorian Mallee, and records of each are summarized. These mammals are discussed under four categories: 15 were inland or W. animals which approached or penetrated the Victorian Mallee only in the Murray-Darling area and none of which has been recorded there for about a century; 6 species (4 of which are still extant) belonged to less arid inland habitats, and occurred about the Mallee and in adjoining woodland areas of N. and W. Victoria; 3 are typically Mallee species still extant in the region; and 17, which are widespread in Victoria today, extended more or less into the Mallee. The Victorian Mallee is thus shown to have been the meeting place of two distinct faunas—the one of arid inland Australia and the other of C. and S. Victoria.

Vegetation

Most of the Victorian Mallee originally carried a mallee-eucalypt vegetation but, with the spread of agriculture, much of this formation has been eliminated. Most of the remnant lies between the South Australian border and a N.-S. line from Mildura to Horsham. In this W. sector there are three major units of natural habitat, the Little Desert, the Big Desert, and the Sunset Country.

The Little Desert is an E.-W. zone of sandy heathland practically devoid of mallee-eucalypts but carrying a little brown stringybark (*Eucalyptus baxteri*). Adjoining this desert on the N. side is a tract of typical mallee-eucalypt vegetation, which in turn gives way to the woodland formation of the Nhill-Kaniva district. This woodland is not properly part of the Mallee but is similar to extensive tracts lying S. and SE. of that region. It isolates the Little Desert habitat from the rest of the Mallee.

The Big Desert is a comparatively large tract of sand plains and dunes carrying mainly a mixture of heath vegetation and mallee-eucalypt. Intruding into it, the Pine Plains unit is an area of grassland and savannah. The Big Desert is bounded to the north by an E.-W. zone, about the Ouyen Highway, of somewhat fertile sandy loam, the natural vegetation of which is comparatively dense mallee-eucalypt formation.

The Sunset Country is sand, generally with sparse mallee-eucalypt vegetation but with a number of open plains. A few areas, notably the Raak Plain, are saline and carry saltbush.

From about Red Cliffs westward there were originally open formations such as grassland, savannah, and pine-belar woodland. Saltbush plains reappear N. of the Sturt Highway, and finally there are the gum-box woodlands of the Murray R. flood-plains.

Main roads, general areas, and localities cited in this paper, as well as original limits of mallee vegetation, are illustrated in Fig. 1.

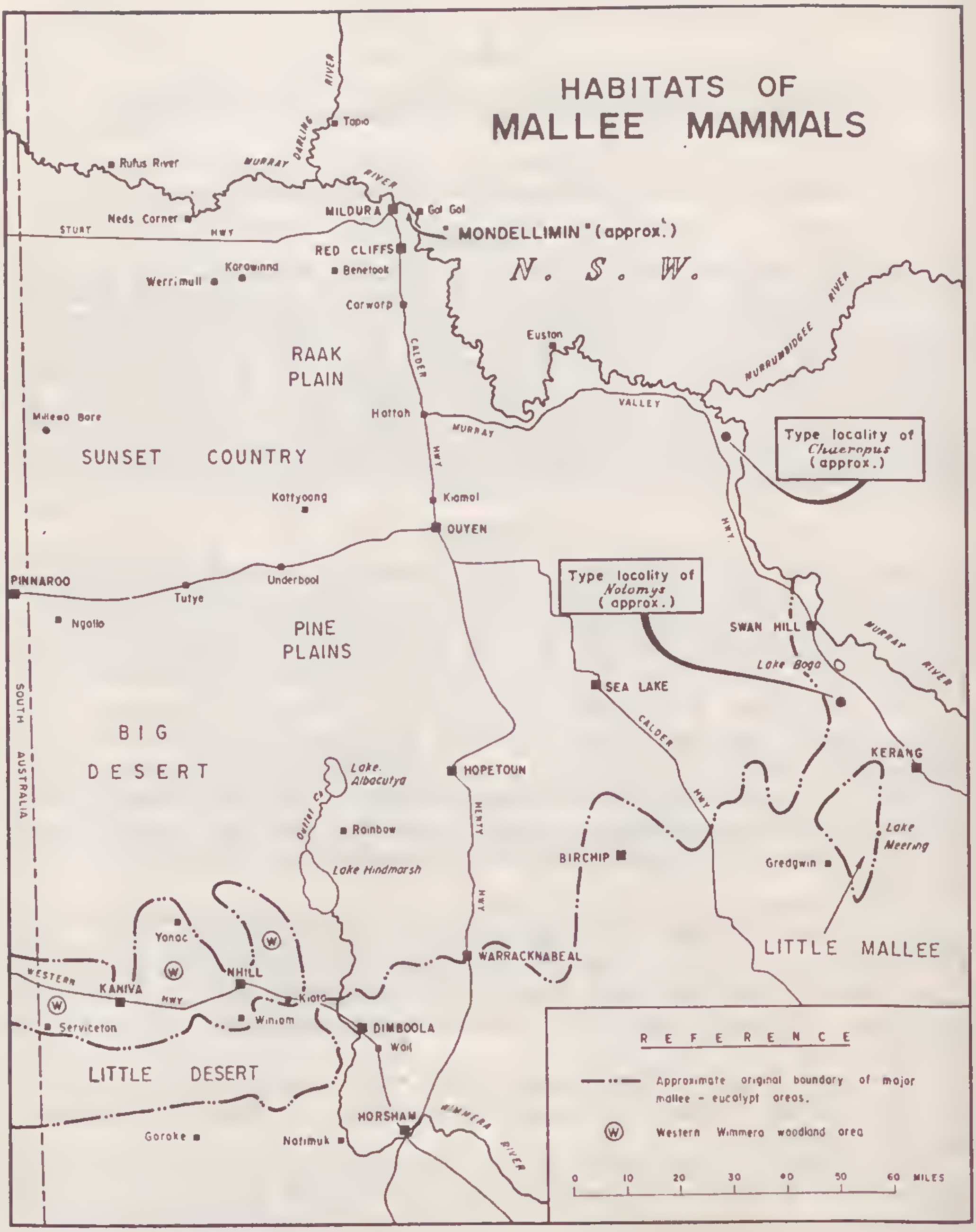
HABITATS OF
MALLEE MAMMALS
N. S. W.
MONDELLIMIN (approx.)
Type locality of Chaeropus (approx.)
Type locality of Notomys (approx.)
Rufus River
Tapio
Neds Corner
MILDURA
Gol Gol
RED CLIFFS
Benetook
Karawinna
Werrimull
Carwarp
Euston
RAAK PLAIN
Hattah
Millewa Bore
SUNSET COUNTRY
Kattyoong
Kiamal
OUYEN
PINNAROO
Tutye
Underbool
Ngallo
PINE PLAINS
SWAN HILL
Lake Boga
SEA LAKE
BIG DESERT
Lake Albacutya
HOPETOUN
KERANG
Rainbow
Lake Hindmarsh
BIRCHIP
Gredgwin
Lake Meering
LITTLE MALLEE
Yanac
NHILL
KANIVA
WARRACKNABEAL
Kiata
Serviceton
Winiam
DIMBOOLA
Wail
LITTLE DESERT
HORSHAM
Goroke
Natimuk
SOUTH AUSTRALIA
MURRAY RIVER
DARLING RIVER
MURRUMBIDGEE RIVER
WIMMERA RIVER
STURT HWY
CALDER HWY
MURRAY VALLEY HWY
HENTY HWY
WESTERN HWY
REFERENCE
Approximate original boundary of major mallee - eucalypt areas.
Western Wimmera woodland area
0 10 20 30 40 50 60 MILES

FIG. 1

Sources of Data

Specimens in the National Museum of Victoria provide the main body of information, and some additional material is cited from the mammal collection of the Fisheries and Wildlife Department of Victoria. The abbreviations NMV and FWD respectively are used for these institutions.

The museum specimens of bats (Molossidae, Vespertilionidae) cited in the present paper have been identified by R. M. Ryan, lately curator of mammals at the NMV and a specialist in the study of Microchiroptera. The taxonomy used hereunder for bats is that currently adopted by the CSIRO Division of Wildlife Research; otherwise, with the exceptions indicated in the text, names of mammals are according to Iredale & Troughton (1934).

An analysis has been made of records of the Blandowski expedition of 1857. This provides some locality data less vague than the citation 'Junction of Murray and Darling' that has been applied universally to Blandowski material located in the NMV. Gerard Krefft was responsible for almost all the collecting of mammals for this expedition, and the observations attributed to him in the present paper apply to his experiences during the expedition. 'Mondellimin', the Blandowski base camp, was situated on the S. bank of the Murray approximately where Mildura now is. In the present paper, citations of that locality almost invariably apply to series of specimens which may have originated partly or wholly from either New South Wales or Victoria. These details are discussed fully in a separate paper (Wakefield 1966) which should be read in conjunction with the present one.

In the present paper, some observations are included which are not supported by preserved specimens but which are considered to be valid. Those of the present author are cited as 'N.A.W. obs.'; others are acknowledged to C. R. Crouch of Kaniva and H. R. Hobson of Rosebery.

Mammal Records

ORNITHORHYNCHIDAE

Ornithorhynchus anatinus

FWD: Murray R. at Rufus R. 1963; Swan Hill 1948; Reedy Lake, Kerang 1960.

C. R. Crouch (in litt. 1961) stated that the species is in the Wimmera R. and that a skull was found on one of its sand-banks in August 1959.

TACHYGLOSSIDAE

Tachyglossus aculeatus

Diggings noted in 1964 and 1965 indicate that the species is widespread in heath formations of Little Desert, Big Desert, and the Sunset Country (N.A.W. obs.).

DASYURIDAE

Antechinus flavipes

NMV: Mondellimin 1857.

Krefft found the species plentiful in gum-box forests along the Murray.

Phascogale calura

NMV: Mondellimin 1857.

Sminthopsis crassicaudata

NMV: Mildura 1953; Karawinna 1929; Werrimull 1929; Carwarp 1964; Swan

Hill 1906; Rainbow 1911; Birchip 1904; Warrnacknabeal 1904; N. edge of Little Desert near Kiata 1945; Goroke 1916.

Sminthopsis murina

NMV: Mondellimin 1857.

On 17 April 1965, a specimen was caught in the Big Desert, 13 miles N. of Yanac. It was examined and positively identified before it escaped (N.A.W. obs.).

Antechinomys laniger

NMV: Mondellimin 1857.

Dasyurinus geoffroii

NMV: Mondellimin 1857.

Myrmecobius fasciatus (= *rufus*)

Krefft reported that the species was not to be found near the Murray but that it occurred in the Tapio area near the lower Darling R.

PERAMELIDAE

Isoodon obesulus forma

NMV: Mondellimin 1857.

Krefft found the species plentiful in the lower Murray R. area.

The N. Mallee animals corresponded in size to the *I. obesulus* of Central Australia and to the specimens recorded from the lower Murray, South Australia (Wakefield 1964). They are treated in the present paper as an entity distinct from the much larger form abundant in S. Victoria.

Perameles bougainville (= *fasciata*)

NMV: Mondellimin 1857.

Krefft found the species common about the Murray R. The only other Victorian record is of skeletal remains of unknown antiquity from an owl pellet deposit in the Grampians (Wakefield 1963a).

Macrotis lagotis

NMV: Murray-Darling, N.S.W. 1857.

Krefft obtained the Blandowski expedition specimens in New South Wales, and his comment that it had 'long ago retreated to the north of the Murray' is evidently the sole basis of the statement by Brazenor (1950) that it was 'originally recorded from the north-west of the State'.

Chaeropus ecaudatus

NMV: Murray-Darling, N.S.W. 1857.

Krefft obtained all the Blandowski specimens N. of the Murray, and the type specimen provides the only valid record of the species in Victoria.

Mitchell (1839) reported the capture of the original animal in June 1836, a few miles SE. of the Murrumbidgee junction. The habitat was 'grassy plains bounded by sandhills on which grew pines (callitris) and open forests of goborro (or box trees) . . . nearer the river'.

PHALANGERIDAE

Acrobates pygmaeus

C. R. Crouch (in litt. 1965) reported that a specimen was found near Kaniva in 1956, and a second near L. Booroopki, W. of Goroke, in 1964. The latter record is supported by clear colour photographs.

Cercartetus concinnus

NMV: Mildura 1955; Ouyen 1911; Underbool 1910; Serviceton 1937; Little Desert, 6 miles SE. of Kiata 1961; Wail 1961.

FWD: Nureoung, 10 miles NE. of Natimuk 1962 (Type of *C. c. minor*).

Wakefield (1963) described the habitat as mallee and mallee-heath formations where there is sclerophyllous shrubbery in conjunction with eucalypts.

Petaurus breviceps

C. R. Crouch (in litt. 1965) reported that specimens were found 7 miles SE. of Kaniva in 1956 and near South Lillimur, 7 miles SW. of Kaniva, in 1965.

Pseudocheirus peregrinus (= *laniginosus*)

Krefft found the species very rare in the Murray-Darling area in 1857, and there is no other Mallee record of it.

Trichosurus vulpecula

NMV: Carwarp 1956; Gredgwin 1962; Yanac 1954; Boyeo, 10 miles NW. of Nhill 1961; S. of Kaniva 1965.

Krefft found the species plentiful in the gum-box forests along the Murray and also in tall mallee formation many miles from water.

MACROPODIDAE

Bettongia ~~lesueur~~ penicillata

NMV: Mondellimin 1857.

Krefft found the species along the Murray westward from about Euston, and he noted its partiality to *Polygonum* thickets.

Bettongia lesueur

NMV: Murray-Darling, N.S.W. 1857.

Krefft obtained all the Blandowski expedition specimens in New South Wales.

[*Aepyprymnus rufescens*

NMV: Gunbower and Echuca 1856-7.

Krefft did not encounter the species W. of Reedy Lake (Kerang), and it cannot be considered as a Mallee species.]

Lagorchestes leporides

NMV: Murray-Darling 1857.

Krefft's experience with the species was mainly or wholly between the Murray and Darling, particularly in saltbush country.

Onychogalea fraenata

NMV: Mondellimin 1857.

Krefft found the species plentiful from about Gunbower to the Murray-Darling area, and he noted its preference for scrub-covered sandhills.

In 1959 a sub-fossil skeleton of unknown antiquity was found near L. Hindmarsh; it is lodged in the Mines Department Geological Museum, Melbourne.

Onychogalea lunata

NMV: W. of Darling R., N.S.W. 1857.

Wallabia rufogrisea

FWD: 8 miles SW. of Kaniva 1966.

Several sightings in 1965 demonstrate that the species occurs also on the N. fringe of the Little Desert both SW. and SE. of Kaniva (N.A.W. obs.).

Macropus rufus (= *Megaleia*)

NMV: Benetook 1949.
FWD: Ned's Corner 1960.

Macropus major

NMV: Swan Hill 1911; Winiam 1921.
FWD: Mildura 1960; N. of Hattah 1962.

On the evidence of the sighting of many animals and innumerable tracks in areas investigated during 1964 and 1965, this species is recorded as widespread and abundant in the Mallee (N.A.W. obs.).

Over 50 years ago, LeSouef (1887), French (1889), and Mattingley (1909) found it plentiful near L. Albacutya, towards Red Bluff station via Bordertown, and in the Pine Plains area, respectively.

These observations apply mainly or wholly to the Black-faced Kangaroo, *M. m. melanops*, but the relationship of this Mallee form to the common Grey Kangaroo is not considered in this paper.

MURIDAE

Hydromys chrysogaster

NMV: Mildura 1953, 1962; L. Boga 1857.

H. R. Hobson (in litt. 1962) reported observation of two specimens in Outlet Ck near L. Albacutya in 1958.

[*Thetomys gouldii*

The single NMV specimen registered as 'Junction of Murray and Darling' was evidently brought back by Blandowski from his Darling R. excursion, and the species cannot be recorded as Victorian or even from the lower Darling area.]

Leggadina hermannsburgensis

NMV: Murray-Darling 1857.

Krefft indicated that the species had a general distribution in the scrubs of the lower Murray R. district. It is reasonably certain that some of the many specimens he collected were obtained in the N. part of the Victorian Mallee.

Gyomys apodemoides

NMV: Little Desert, S. of Kiata 1940, 1957.

Field work in 1964 and 1965 has established that the species is widespread and abundant in undulating heath and mallee-heath formations of both the Little Desert and Big Desert (N.A.W. obs.).

Gyomys desertor (= *Mus subrufus* Krefft)

NMV: Murray-Darling 1857.

Krefft referred to the abundance of this species between Gol Gol and the Darling R., and he neither affirmed nor denied its occurrence S. of the Murray. It is highly probable that some of the many specimens he collected were obtained in Victoria.

Leporillus apicalis

NMV: Mondellimin 1857.

Krefft found the species on both sides of the Murray R. from about Euston westward.

Leporillus conditor

NMV: Tapio, N.S.W. 1857.

The acceptance that this species once occurred in the Victorian Mallee is based on Krefft's report of its empty stick houses to the south of the Murray R.

Notomys mitchellii

NMV: Mondellimin 1857; Hattah 1965; NE. end of L. Albacutya 1956; near Rainbow 1962; 8 miles E. of Yanac 1955.
FWD: 8 miles NE. of Kiamal 1965; S. of Tutye 1965; Ngallo 1965.

The type specimen was obtained in June 1836 several miles SE. of L. Boga, Victoria (*vide* Mitchell 1839).
Krefft encountered the species in abundance from the Murrumbidgee westward to about the Darling.
A recent survey has shown that in the Hattah area and about the Big Desert its habitat is scrub-covered sandhills associated with mallee-eucalypt formation (N.A.W. obs.).
On the evidence of an observation reported to him, Brazenor (1936) recorded *Notomys* from near Goroke, but this is suspect as there is no valid record of the species from the Little Desert area.

CANIDAE

Canis familiaris dingo

NMV: Mondellimin 1857.

Krefft found the dingo plentiful about the Murray R., despite poisoning by settlers.
French, LeSouef, and Mattingley (l.c.) indicated that it was still abundant in mallee areas about the turn of the century.
Records of the Vermin and Noxious Weeds Branch of the Department of Lands and Survey, Victoria, show that for 1963 and 1964 an aggregate of 18 wild dogs or dingoes were destroyed in the Shire of Lowan, W. Wimmera.
Remains of two kangaroos, with large bones broken and chewed dog fashion, in the vicinity of Salt Lake, 13 miles S. of Kiata, in December 1964, established that wild dogs or dingoes had recently been in that section of the Little Desert; and several sets of fresh dingo tracks were found near Millewa Bore, Sunset Country, in September 1965 (N.A.W. obs.).

MOLOSSIDAE

Tadarida australis

NMV: Warracknabeal 1927.

C. R. Crouch (in litt. 1961) reported examining examples of this species in September 1959 from two localities on the S. fringe of the Big Desert: one from Murrawong, N. of Kaniva, and several from approximately 6 miles N. of Kiata.

Tadarida planiceps

NMV: Red Cliffs 1954; 18 miles N. of Underbool 1963; L. Meering 1962, 1963; Kiata 1963; Kaniva 1961.

VESPERTILIONIDAE

Chalinolobus gouldii

NMV: Mopoke Tank, Sunset Country 1961; Perry Tank, Sunset Country 1963; L. Meering 1962, 1963; Rainbow 1962; S. of Kaniva 1961.

Eptesicus pumilus

NMV: Mildura 1961; Hattah 1951; Mopoke Tank 1961; Kattyoong 1962; L. Meering 1962, 1963; W. Wimmera 1961.

Nyctophilus geoffroyi

NMV: Raak 1918; Mopoke Tank 1961; Ouyen 1910; Little Desert, S. of Kiata 1961.

Nyctophilus timoriensis

NMV: Mopoke Tank 1961; Ouyen 1910.

Nycticeius balstoni

NMV: Red Cliffs 1922; Pink Lakes, NW. of Underbool 1963; S. of Kaniva 1960.

Discussion

Many of the mammals encountered by Krefft in 1857 were inland or W. species of arid habitats which, as far as is known, approached or penetrated the Victorian Mallee only in the Murray-Darling area. The following 15 species are in this category.

Myrmecobius fasciatus, Macrotis lagotis, Bettongia lesueur, and *Onychogalea lunata* were found N. of the Murray R., and there is no evidence that any of them occurred in Victoria in modern time. Nevertheless, any of them may have been present, immediately prior to European settlement, in the N. fringe of the Victorian Mallee.

Phascogale calura, Antechinomys laniger, Dasyurinus geoffroii, Isoodon obesulus forma, *Perameles bougainville, Chaeropus ecaudatus, Bettongia penicillata, Gyomys desertor, Legaddina hermannsburgensis, Leporillus conditor*, and *Leporillus apicalis* are accepted as having occurred on the Victorian side of the Murray. Nothing further is known of the distribution of any of these, as modern animals, in this State, though it is likely that at least some were widespread about the Mallee.

None of the 15 mammals listed above nor the first two of the next category below has been recorded in or near Victoria since the 1860s. Marlow (1958) records a similar situation with the marsupials of W. New South Wales, where 'the smaller plain-dwelling members . . . without exception have been reduced to rarity or extinction'.

A second category comprises species of less arid habitat, which were formerly widespread in inland areas of New South Wales and which occurred in woodlands of N. or W. Victoria as well as about the Mallee. These include *Lagorchestes leporides, Onychogalea fraenata*, and *Macropus rufus*, all of which are represented in the NMV collections by specimens from the Echuca-Gunbower district, well to the east of the limits of the Mallee.

Three small species—*Sminthopsis murina, Tadarida planiceps*, and *Nycticeius balstoni*—are in the same category, extending into the Mallee and the W. Victorian woodlands.

A third category comprises *Cercartetus concinnus, Gyomys apodemoides*, and *Notomys mitchellii*, all of which are today plentiful in central Mallee areas. In Victoria none of these occurs outside the Mallee.

The fourth category comprises 17 mammals that are widespread in Victoria and which extend more or less into Mallee areas:

Acrobates pygmaeus, Petaurus breviceps, and *Wallabia rufogrisea* are each recorded only from the southernmost Mallee unit. They are known from areas marginal to the Little Desert.

The two aquatic species, *Ornithorhynchus anatinus* and *Hydromys chrysogaster*, are apparently confined in the Mallee to waters associated with the Murray and Wimmera Rivers.

Antechinus flavipes and *Trichosurus vulpecula* are marginal, in woodlands or along streams where large trees provide suitable homes.

Sminthopsis crassicaudata, widespread in woodlands from NE. to SW. Victoria, penetrates the Mallee in much of the mallee-eucalypt formation.

Available records of the four small bats, *Chalinolobus gouldii, Eptesicus pumilus, Nyctophilus geoffroyi*, and *N. timoriensis*, indicate that each occurs deep in the Mallee, but data about the larger *Tadarida australis* suggest that it may be marginal, in areas carrying larger trees.

The dingo survives in remote places, and *Macropus major* is widespread and abundant in the Mallee.

The apparent absence of *Pseudocheirus peregrinus* from woodlands marginal to the Mallee suggests that Krefft's 1857 record and the specimens in the Fromm's Landing excavation (Wakefield 1964) may have represented a lower Murray R. population of the species discrete from that of S., C., and E. Victoria.

Krefft was definite that, when he was at 'Mondellimin', *Tachyglossus aculeatus* was unknown in the lower Murray R. district. Now it is widespread in the Mallee including, according to local naturalists, the Mildura area. These data indicate that the echidna has spread into the northern Mallee during the past 100 years.

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VEGETATION STUDIES IN NORTH-WEST VICTORIA
II. THE HORSHAM AREA

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Summary

The soil and vegetation interrelationships of an area of the Wimmera Region of Victoria are discussed. The original vegetation formations of the area have been reconstructed and mapped from remnants preserved along road reserves. Four savannah woodland communities, *Eucalyptus largiflorens* association, *E. hemiphloia* asociation, *E. leucoxylon* asociation, and *Casuarina leuhmannii* association, intergrade considerably to comprise the vegetation of the major part of the area. Because of the extensive clearing that has been undertaken, it is often difficult to distinguish the original areas of savannah woodland from the former grassland formation, *Stipa-Danthonia* association.

Introduction

The soils and vegetation of an area of 300 square miles of the Victorian Wimmera Region were surveyed from all passable roads and from many traeks. The area is located on aerial photomap Horsham 880 and is shown inset on the map of Vietoria (Fig. 1). No aecount of the vegetation of the Wimmera is avail-

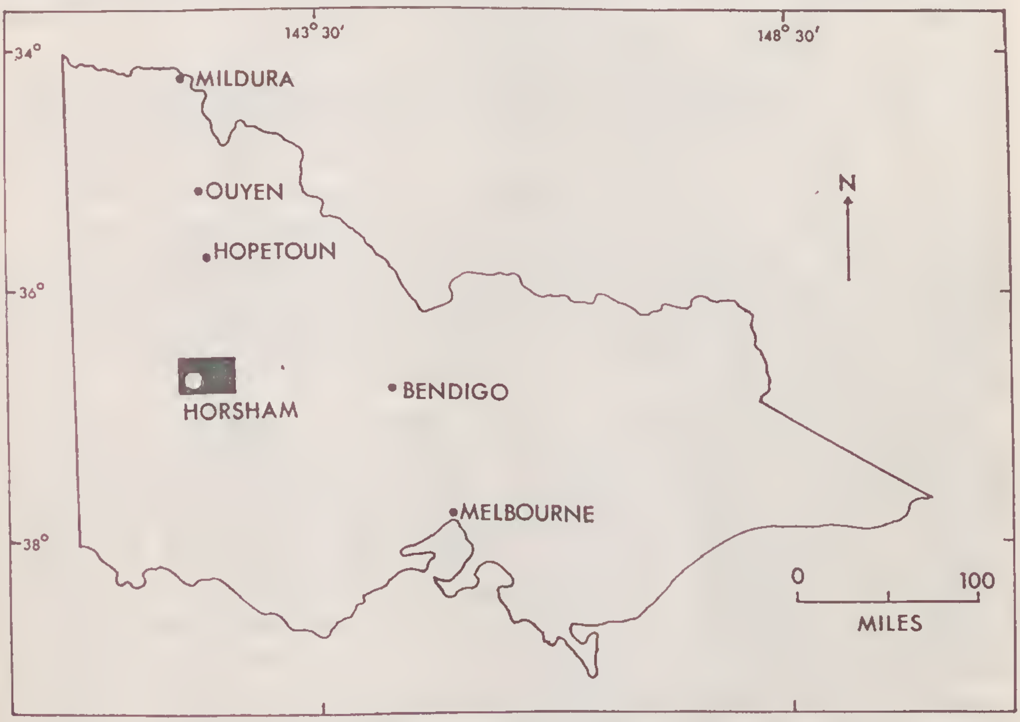

FIG. 1—Location of the area.

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able, although various publications (Leeper 1957; Skene 1954, 1959) have made passing comments about the savannah woodland communities which comprised a great part of the area. In South Australia, a survey near the Victorian border (Specht 1951) dealt in detail with country with many similarities.

Large scale clearing has resulted in the removal of most of the original vegetation. At the present time one of the most conspicuous species over much of the area is *Eucalyptus cladocalyx* F. Muell. (sugar gum), a South Australian endemic, which was extensively planted at the beginning of this century. It is exceptionally difficult, therefore, to delineate the distribution patterns of the native tree species. Close interrelationships of the soils of the area are a conspicuous feature of the landscape and mapping of their variation is difficult.

Geology and Physiography

During Lower Cretaceous times, earth movements caused the formation of the Murray Basin in South Australia and SE. Victoria. They continued into the early Tertiary and the Basin increased in size to include part of the Wimmera. At this time a bedrock fault situated 6 miles W. of Dimboola and trending NNW. prevented further easterly invasion of the sea. However, by Mid-Tertiary, subsidence of both E. and W. blocks enabled the Gulf to extend across the Dimboola Fault. Bore logs show that 420 ft of the Lower Cretaceous carboniferous sands and clays found at Nhill have no equivalent at Kewell on the high E. block (Anon. 1961).

In Pliocene times gradual uplift caused the sea to retreat. The NNW. ridges, which are a noticeable feature of the W. Wimmera and to a lesser extent of the E. Wimmera, are considered to be stranded coastal dunes of the retreating Murray Gulf (Blackburn 1962a). Two such dunes occur in the study area. They are situated approximately one mile apart and govern the course of the Yarriambiac Ck from Jung northwards towards Hopetoun.

Estuarine clays and sands were deposited over the greater part of the area by rivers and lakes which drained the newly exposed surface. Blackburn (1962b) considers that the distribution of the Wimmera clay soils indicates the location of an earlier Glenelg R. S. of the present town of Horsham. The river altered its course when the exposed plain was uplifted and tilted to the north. This movement probably occurred along the Dimboola Fault. The Murray R. came to occupy its present course, while its lower reaches became the present Glenelg R. and the upper reaches the Wimmera R. By a reversal of flow resulting from the same tilting phenomenon, the Wimmera R. occupied a former southward flowing river valley between Quantong and Jeparit. The same movement probably accounts for the northward flowing courses of the Yarriambiac and Dunmunkle Ck which are effluents of the Wimmera R.

In the Pleistocene and Recent Periods addition of wind borne and saltation material from the west have caused the formation of characteristic structures—lunettes, which are a common feature of the E. margins of now dried-up lakes. The lunettes associated with the Wimmera R. are sandy, indicating that in the past this river was more active and carried a greater sedimentation load than at the present time. Slowing down of the river, where it makes a sharp turn to the north at Quantong, could result in the deposition of sandy material on the E. bank. Such materials would then be transported under the action of the prevailing westerly winds, providing the materials from which the lunettes may have been formed.

The presence of laterite in the stranded coastal dunes near Jung shows that pluvial periods have been a feature of the immediate past climate. A quarry 2 miles N. of Dooen reveals friable black soil 4 ft deep, sharply overlying laterized sandstones. Presumably the old Pliocene surface was subjected to laterization during a pluvial period and later, under even wetter conditions, became a basin of deposition into which the parent material of the now exposed black friable soil was deposited. This area is considered to be one of the most recently exposed areas.

The land surface slopes gently to the north and two northward flowing effluents of the Wimmera R. have arisen. One of these, the Yarriambiac Ck, arises in the area and terminates in L. Coorong near Hopetoun. It does not flow continuously, but is dependent upon high winter-spring levels of the Wimmera R. for replenishment. From Jung to Hopetoun the creek flows in a broad, well-defined valley between the dunes previously mentioned. Before it enters this valley at Jung, water can easily escape the normal creek course. Apparently the S. extremities of the dunes have been eroded away by lateral planation across the flood plain of the Wimmera R. In wet years water spreads both E. and W. To the east it floods the country S. of Murtoa around 'Black Fellas' Waterholes', joining up with temporary creeks in that area. To the west the water enters Darlot's Swamp. When this swamp overflows, water returns to the south across the low land to the east of Longeronong Agricultural College, and finds its way back to the Wimmera R. approximately 8 miles downstream from where it originated as an effluent.

The flatness of the area and the precarious drainage relationships are clearly illustrated by this example. Shallow expanses of water lying over large areas are not uncommon, and were it not for surfaced roads, many areas of the Wimmera would be impassable to motor vehicles for most of the winter and early spring months.

Climate

Data from the Commonwealth Bureau of Meteorology (Melbourne) show a range in annual rainfall from 17·5″ at Horsham to 15·7″ at Jung. Fig. 2 summarizes meteorological data for Horsham. 40% of the rainfall falls in the summer and autumn months. Early and late frosts do occur, giving an average frost-free period of 207 days.

Soils

In general, the soils have developed on alluvial and lacustrine deposits of the drainage system of the Pliocene Murray Basin Plain. The only exceptions are the soils formed on the two parallel stranded coastal dunes which represent an older Pliocene land surface. The boundary of these latter soils is not sharply defined, for they intergrade with the alluvial deposits. The effect of the dunes is more pronouced on the country to the east of Jung, an expression of the dominance of westerly winds. Here, for some 6 to 8 miles, there is a strong inter-mixing of light-surfaced red brown earth (R.B.E.) soils with grey and brown soils of heavy texture (G.B.S.H.T.) (nomenclature per Stephens 1956). Even farther to the east the soils between Murtoa and Rupanyup are the more typical, self-mulching G.B.S.H.T. of the Wimmera plains. To the south-east of Murtoa, Pleistocene and Recent sediments contained a predominance of coarser material, most likely a reflection of a more vigorous drainage pattern—rivers and streams as opposed to lakes. On these sediments R.B.E., G.B.S.H.T., and transitional soils are closely intermixed.

Previous work on the soils of the Victorian Wimmera is limited to two small areas (Skene 1954, 1959) located 5 miles W. of Horsham and 8 miles N. of Murtoa respectively. Both of these surveys show the close interrelationships be-

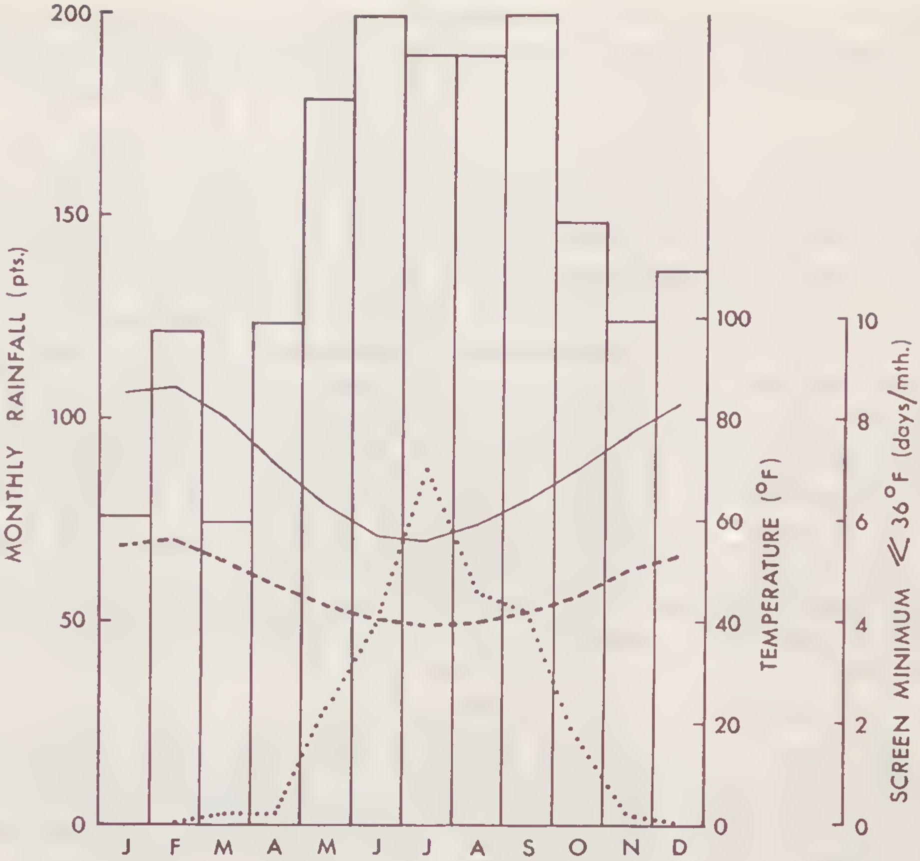

FIG. 2—A summary of climatic data for Horsham. Histogram of monthly rainfall. Mean monthly maximum (——) and mean monthly minimum (– – –) temperatures, and the monthly frequency of screen temperatures equal to or less than 36°F (···).

ween members of the Great Soil Groups, the R.B.E. and the G.B.S.H.T. Even though each report covers only 5 square miles, and in both cases detailed work was required for proposed irrigation schemes, it was found necessary to use soil complexes for mapping and description. From a pedological viewpoint there is a great range of parent materials, all are sediments but mechanical and probably chemical composition vary greatly over the area as a whole.

Since the area shows little topographical variation, climatic variations are small and hence vegetational changes clearly follow soil variation. Leeper (1957) justly cautioned the use of vegetational criteria in soil mapping because climate, as well as soil, is important in governing the distribution of vegetation. He uses as an example the vegetation of the Victorian Wimmera, pointing out that buloke (*Casuarina luehmannii*) grows over a great portion of the area, and yet the gilgai soils between Glenorchy and Rupanyup are not held as highly in esteem as are the soils under buloke in other areas. A better example is needed to prove his point, for in this area between Glenorchy and Rupanyup a prominent additional species, yellow gum (*Eucalyptus leucoxylon*), is present. This tree which is characteristic of R.B.E. soils in South Australia (Specht & Perry 1948, Specht 1951), and which extends on to solodic soils S. of Glenorchy, gives an immediate clue to a soil difference. Actually the soils in this area have R.B.E. tendencies and true G.B.S.H.T. are rare. The important point here is that a knowledge of the complete range of species is essential, and then the important or critical species, if one occurs, can be discovered. In this case, buloke is an ecological wide; yellow gum can be regarded as the indicator species.

Although topographical information is not available, stock and domestic water channels indicate that the area N. of the Wimmera R., between Pimpinio and Dooen, is low-lying and probably one of the most recently exposed areas—a product of an internal drainage system. The soils of this area, the 'Kalkee Plain', differ from the more typical G.B.S.H.T. found on either side of the Western Highway SE. of Horsham, on which most previous observations have been made. Vegetational differences reflect this also, for although the area S. of the river previously carried a savannah woodland of grey box (*Eucalyptus hemiphloia*) and buloke, the 'Kalkee Plain' was a true grassland formation. On this 'plains' area, surface soils of puff and hollow in the gilgai complex are high in lime and extremely self-mulching. Trees, notably sugar gum, can be established if watered during the first few summers, but under virgin conditions only perennial grass species could persist through the summer months. These soils are more easily cultivated, and arable more quickly after rain than their counterpart of the woodland areas S. of the river. This soil difference is reflected in the farming practice, for wheras cereal production is intense on the self-mulching soils, the non-friable G.B.S.H.T. are used predominantly for pasture production.

Gilgai, with their colour and microtopographic variations, are a noticeable feature of almost all soils of the area. All the G.B.S.H.T. show gilgai structure as do also some transitional R.B.E. The form of the gilgai can vary from well-defined puffs and hollows, a matter of 2 yds apart and with 2 to 3 ft difference in elevation, through a whole range to the case where puffs are broad (30 ft) and barely distinguishable. Blackburn & Gibbons (1956) showed in Kowree Shire that some soils of the hollows in the gilgai complex were solonetzic. No such soils were seen in this area. All puff soils are self-mulching but not so the soils of shelf or hollow. In some cases there is no evidence of a hollow being present at all. Constant cultivation has caused 'ironing out' of most gilgai structures; however, observation on roadsides indicates that they were extensive over the whole of the Wimmera region.

Descriptions of representative profiles are given in Appendix 1. Skene (1954, 1959) provides more precise information on the physical and chemical characteristics of the soils of the area.

Vegetation

The original vegetation of the Wimmera consisted for the most part of a savannah woodland sub-formation (terminology per Wood & Williams 1960), with *Eucalytus hemiphloia* (grey box), *E. largiflorens* (black box), *E. leucoxylon* (yellow gum), *E. camaldulensis* (red gum), and *Casuarina luehmannii* (buloke) as the dominants. Most combinations of these species can be found. In the E. section of the Wimmera, at least, a grassland formation did exist, and one of these, the 'Kalkee Plain', is situated between Pimpinio and Dooen in the area studied. Another is found between Murtoa and Rupanyup, and a third, the 'Lallat Plain', occurs E. of Rupanyup.

SAVANNAH WOODLAND SUB-FORMATION

(i) Dominant Species:

All savannah woodland communities intermix with each other, but insufficient vegetation remains to use a quantitative approach to separate the communities involved in the vegetational continuum (e.g. positive interspecific correlation as was used in the Beulah area (Connor 1966). Therefore, it seems preferable to discuss the autecology of each dominant species, mentioning interrelationships as they arise.

Eucalyptus camaldulensis (red gum)

This species does not extend beyond the watercourses and swamps of the area. In these localities it forms a well-developed savannah woodland, often in association with *E. largiflorens* (black box). *E. camaldulensis* fringes the Wimmera R. but is not common along the Yarriambiac Ck, being present only in places where permanent or near permanent waterholes occur. In the vicinity of 'Black Fellas' Waterholes' and also in the Dooen Swamp there is evidence of regrowth of *E. camaldulensis*. This is probably related to the very wet winter and spring of 1956, when conditions suitable for germination occurred.

The distribution of this species is insufficient for it be included on the vegetation map of the area (Fig. 3).

Eucalyptus largiflorens (black box, flooded box)

Black box is confined to areas subject to infrequent flooding. It is more drought resistant than red gum and can survive on soils which dry out and crack deeply in summer, provided that this is an uncommon occurrence, and that during the winter months the soil is again fully recharged with water. In some situations it forms a scrubby community which can hardly be termed a woodland. Typically, however, it is a well-grown tree with a woodland form. Lignum (*Muehlenbeckia cunninghamii*) is commonly associated with it on wetter sites.

Most suitable areas for the growth and development of black box are found in association with watercourses, or with low-lying land which is generally wet in winter and spring. However, it does occur in small pockets or as single trees at points of impeded drainage in generally better drained land. Such positions occurred in the grassland formation, and indicated to the early settlers the appropriate places at which to construct water storage structures.

Eucalyptus hemiphloia var. *microcarpa* (grey box)

This species is often confused with *E. largiflorens*. The two species hybridize and this makes identification difficult in some cases. *E. largiflorens* has a spreading habit with branches which often touch the ground. *E. hemiphloia* on the other hand is typically half-barked, with a lighter basal bark, has an upright habit and no tendency to have drooping branches.

E. hemiphloia grows in association with *Casuarina luehmannii* as a savannah woodland S. of the Wimmera R. It is not found with *E. largiflorens* along the Yarriambiac Ck but grows with *C. luehmannii*, *E. largiflorens*, and *E. leucoxylon* in the vicinity of 'Black Fellas' Waterholes'. The controlling feature appears to be a requirement for a slightly better drained soil than those upon which *E. largiflorens* flourishes.

E. hemiphloia extends eastwards on the red brown earth soils of north-central Victoria.

Eucalyptus leucoxylon (yellow gum)

This is not a common species. It is widespread, however, and is found in locations where the soil has a lighter surface texture than the usual G.B.S.H.T. provide. It occurs alone on the sandy lunettes associated with the Wimmera R. and to the east, between Glenorchy and Rupanyup, it accurately delineates the R.B.E. and transitional soils with their suitable moisture relationships.

E. leucoxylon extends on to the solodic soils S. of Glenorchy.

Casuarina luehmannii (buloke)

This is the most widespread species. It grows under a wide range of soil conditions and can readily be found in association with all the tree species mentioned above. It grows alone on the country bordering the Yarriambiac Ck, and in some areas to the east of the creek between Jung and Murtoa. The soils in these situations are R.B.E. derived from the two stranded coastal dunes which border the creek. To the early settlers this 'buloke' land presented a contrast to the grassland ('plains') found both to the east and to the west. The earliest survey plans (Central Plans Office, Melbourne) have notes to the effect that this 'sandy soil timbered with Oak' was regarded as 'good agricultural land'. Apparently the settlers considered the 'plains' poor land. If it could not support trees, then how could it be expected to grow crops or pastures? Consequently, none of the earliest land selections is located on 'plains' country. This classification has since been proved to be disastrously wrong, for wheat yields of 60-70 bushels per acre are commonplace on the black 'plain' country; the red sandy soils, which once carried pure buloke, produce crops in the order of 18-20 bushels per acre and suffer from surface sealing problems.

As is the case with black box, buloke does not always occur in a savannah woodland sub-formation (TG (m.d.)). In some locations the structure of the community is more aptly described as a sclerophyll scrub sub-formation (T/S_1S_2(d)). Since most of the area is now cleared of timber it is not known how extensively buloke grew in this manner. Probably these occurrences were rare or they would have been noted on the early survey maps. As it is, most notes refer to 'lightly timbered country'.

Other Tree Species—

Other species of only limited occurrence are *E. viminalis* (manna gum) on the sandy lunette which forms the Horsham Golf Club, *Banksia marginata* (honeysuckle) and *Callitris preissii* (pine) found on the Horsham lunette, on another lunette at Dooen, and on a sandy area amidst the *E. hemiphloia-E. leucoxylon* savannah woodland adjacent to 'Black Fellas' Waterholes'.

E. melliodora A. Cunn. (yellow box), though not recorded in the study area, is found in country to the immediate east. It is commonly found in sites where sand or gravel lenses occur near the surface (G. Blackburn pers. comm.).

(ii) Associations:

An attempt to describe the associations of the savannah woodland sub-formation has been made in Table 1. The difficulty is that a great part of the study area is a close mixture (ecotone) between four associations which, as pure stands, occupy significant areas in other parts of Australia. These are *E. largiflorens* association, *E. hemiphloia* association, *E. leucoxylon* association, and *Casuarina luehmannii* association. Another possible treatment (Beadle & Costin 1952) would be to call each separate admixture an association. In this case the 17 possible combinations

TABLE 1

The Ecological Relationships of the Vegetation Around Horsham

<table>
<tr><th>Formation</th><th>Community</th><th>Structural Formula</th><th>Rainfall (in. per annum)</th><th>Soil</th><th colspan="2">Comments</th></tr>
<tr><td rowspan="6">Woodland .. .. (Sub-formation Savannah Woodland)</td><td>E. camaldulensis association</td><td>TG(m.d.)</td><td>15·5–17·5</td><td>G.B.S.H.T., R.B.E., transitional soils</td><td colspan="2">restricted to positions where frequent and prolonged floodings occur</td></tr>
<tr><td>E. largiflorens association</td><td>TG(m.d.)</td><td>15·5–17·5</td><td>G.B.S.H.T., R.B.E., transitional soils</td><td>restricted to positions where infrequent floodings occur</td><td rowspan="4">These species are found together over a large portion of the area following small variations in soils and minor topographic fluctuations</td></tr>
<tr><td>E. hemiphloia association</td><td>TG(m.d.)</td><td>17·0–17·5</td><td>G.B.S.H.T., transitional soils</td><td>as a pure stand restricted to heavy soils which are not flooded and which are not self-mulching</td></tr>
<tr><td>Cas. luehmannii association</td><td>TG(m.d.)</td><td>16·5–15·5</td><td>R.B.E. of the Jung dune system</td><td>found only as a pure stand on soils developed on the Pliocene land surface</td></tr>
<tr><td>E. leucoxylon association</td><td>TG(m.d.)</td><td>17·0–17·5</td><td>R.B.E. and transitional soils with a shallow sandy surface</td><td>controlling feature is a requirement for a light textured surface soil over a heavy sub-soil</td></tr>
<tr><td>Callitris preissii–Banksia marginata association</td><td>TG(m.d.)</td><td>17</td><td>deep sands of isolated lunettes</td><td colspan="2">of minor occurrence and restricted to three small patches of deep sand probably originating as sediment from the Wimmera River</td></tr>
<tr><td>Grassland .. ..</td><td>Stipa–Danthonia association</td><td>G.</td><td>16·5–15·5</td><td>G.B.S.H.T.</td><td colspan="2">restricted to those G.B.S.H.T. with a highly self-mulching surface soil</td></tr>
</table>

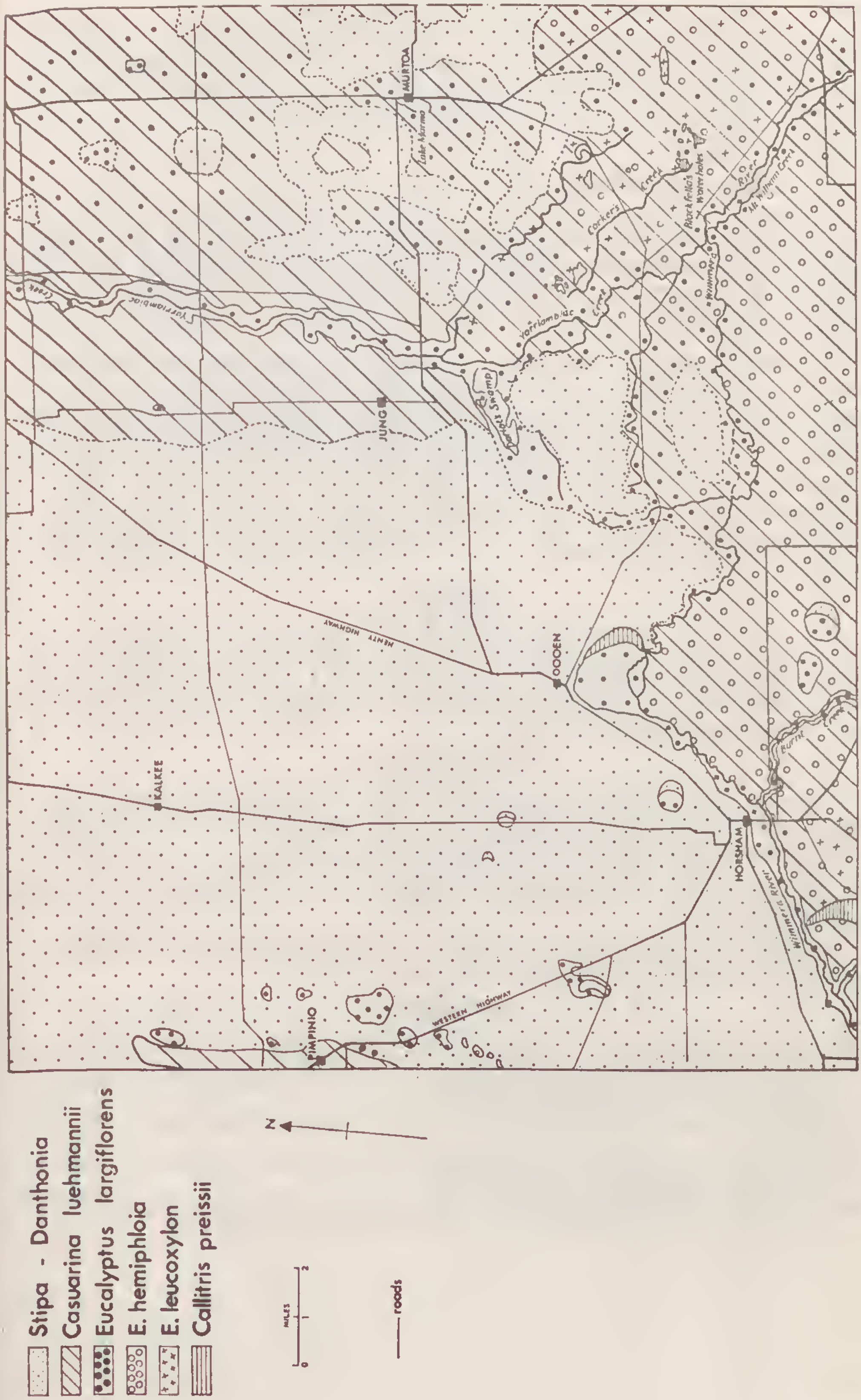

FIG. 3—Vegetation map for the Horsham area.